FACTORY MANAGEMENT COURSE AND SERVICE

A Series of Interlocking Text Books Written for the Industrial Extension Institute by Factory Managers and Consulting Engineers as Part of the Factory Management Course and Service

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THE MECHANICAL EQUIPMENT

BY

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VOLUME 3

FACTORY MANAGEMENT COURSE

INDUSTRIAL EXTENSION INSTITUTE
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PREFACE

The purpose of this book is to present the standard machines and mechanical methods used in general manufacturing, and to show their proper fields.

An industrial executive deals with two general classes of problems: those relating to business, accounting and executive management, and those involving the physical equipment and methods of manufacture. It is not necessary that an executive be able to build every machine he uses, or even that he know all its habits, good and bad, as intimately as the skilled mechanic who runs it. But, in order to act intelligently, he must know the types of machines available for the work in hand, their capacity and relation to each other, and the processes and methods involved.

Modern industrial equipment is almost as varied as the industries themselves, and no single volume could attempt to describe all of it. This book is therefore confined chiefly to the machine shop. As Mr. F. A. Halsey has said: "The machine shop is the center from which all modern industries radiate. From the brickyard to the flying machine, from the sawmill to wireless telegraphy, from the stone quarry to the moving-picture camera, there is no modern industry more than twice removed from the machine shop." Even with the field so narrowed it is necessary to confine the attention to typical machines and to avoid too detailed discussion.

So far as the writer knows no book has yet presented the subject of machine equipment as a whole, or has pointed out the relations of the standard tools to each other. It is the purpose of this book to do so. It is an outgrowth of a course of lectures and recitations given for a number of years to

the students in Mechanical Engineering at the Sheffield Scientific School, Yale University, and presupposes only such technical knowledge or experience as might be possessed by an undergraduate in a technical school or an office man having a general familiarity with manufacturing.

While the book deals chiefly with foundry, forge shop, and machine shop equipment, four chapters have been added to point out the more characteristic features of wood-working, paper, shoe, and textile machinery. In the preparation of these four chapters the writer would acknowledge his indebtedness to Mr. Everett O. Waters, of the Sheffield Scientific School.

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THE MECHANICAL EQUIPMENT

CHAPTER I

BUILDING AND MANUFACTURING

Distinction Between the Two Systems.—Two well-defined methods of production are found in the metal trades, and the principles which differentiate them run through all forms of factory production. No generally recognized names have been given them, and for want of better terms we will call them "building" and "manufacturing." The two systems are sharply differentiated through the entire process of production, and even to marketing. The use of one or the other affects the nature of the whole plant, its methods, and its equipment; consequently before taking up the equipment in detail we will consider the two systems and what they involve.

We shall use the term "building," to cover the production of machines or other articles one at a time, or in numbers so limited that their methods of production are unchanged. By "manufacturing" we shall mean production in lots to standard designs and usually with the corresponding parts interchangeable. As will be seen later, the term manufacturing usually implies a large output, but the distinction lies rather in the methods used than in the quantities produced.

A firm might build a great many things, or manufacture a few. In either case the costs would probably be high. As we shall see, the two systems may be and often are combined in the production of articles where certain details used in great quantities are manufactured, while the larger parts which are not standard are built. This use of the two systems together may often be the wisest and most profitable method of production.

The Building Method.—Perhaps the best way to bring out the characteristics of the building method is to follow the course of a large water-works engine.

The intending purchaser may issue a set of specifications laying down the conditions under which the proposed engine is to operate, the quality of materials to be used, and the capacity and economies to be guaranteed. The firms quoting will draw up preliminary designs and estimate upon them, taking into account patterns available, machinery required for production, transportation, erecting facilities, and so forth. A public hearing may then be held where the advantages of the various designs submitted are argued. These are considered and the contract finally let. The successful firm then makes the drawings covering the details of the entire machine, the patterns that may be necessary, and casts and machines the various parts and erects the engine within its plant. It is then knocked down, shipped to its destination, erected in place, and finally tested under working conditions. As this process requires a long time and heavy expenditure, partial payments may be made at stated stages; but the engine, even when in

place and running, is still in the hands of the builder and is not accepted until the performance guaranteed has been demonstrated. Then and not until then is the transaction closed and the final payment made.

The Manufacturing Method.—Contrast the above with the production of a new model of sporting rifle. A firm manufacturing rifles may determine that a new type of rifle is called for, or some design may be submitted to them which they recognize as desirable. Every available expert is consulted, a design evolved, one or more models "built," and carefully tested under every possible condition of use. Any necessary modification will be made, the details of manufacture carefully studied out, and a sequence of operations determined. A force of tool-makers will be set to work designing jigs, fixtures, gauges, and, if necessary, special machines. The building of these, together with the preliminary work, will run into thousands or even hundreds of thousands of dollars. When actual production is started a large lot will be manufactured and placed in stock, an advertising campaign will be inaugurated, and sales begun. In general, the selling department will begin its activities when the goods are finished and placed in stock. And the marketing of the product is one of business skill and judgment, involving little or no engineering. In the case of the engine, the sale precedes the building and even much of the designing; and the engineer is intimately concerned in the selling as he must convince the purchaser of the superiority of his design. The two processes of production from initial sale to final acceptance follow different courses.

Tools Used in Building.—The contrast runs into the tools used, the methods employed, and even to the type of building best adapted. The building system employs what are commonly called the standard tools —the lathe, planer, shaper, slotting machine, boring mill, drilling machine, and so on. The workmen determine the dimensions of the work and the adjustment of the cutting tools for each piece by direct measurement, and check the work with standard measuring tools and calipers—operations which call for a skilled mechanic. The building used for this large work usually contains a large open bay (see A, Figure 1) with complete crane service, providing room for heavy machine tools, work in progress, erecting floor, etc. On each side of this bay will be one or more floors (B and C) equipped with smaller tools, producing the minor pieces which move out to the

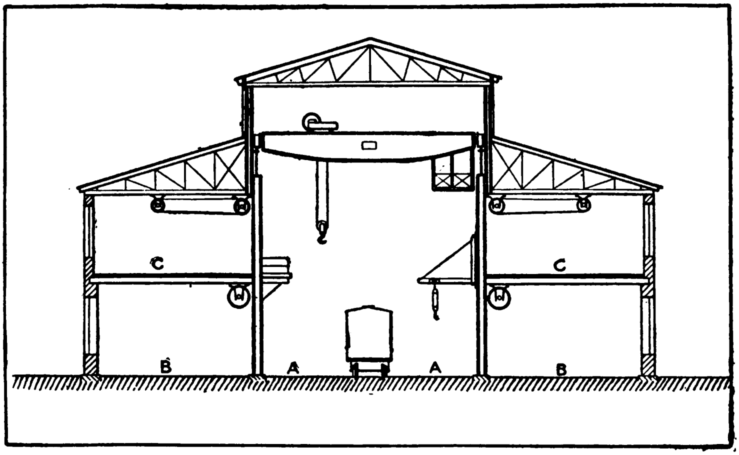

FIG. 1. TYPE OF BUILDING ADAPTED TO LARGE AND SPECIAL WORK

center as the work is completed. The middle bay may have standard railway tracks and connections, so that the rough castings may be brought in from the foundry or elsewhere and the finished product loaded on cars under cover with the use of the crane equipment.

The type of tools and the building system in general were developed in England a little over a century ago by early English mechanics, such as Maudslay, Roberts, Nasmyth and Whitworth. In later years large special tools, such as armor-plate planers, special drilling machinery, and the forging machinery used in American bridge work, will be found in building plants, but they are special only in so far as they are adapted to a certain type of work. They call for skilled attendants, however, and the size of the work is determined by direct measurement. Most of the standard tools used in building were developed before 1850; since that time they have increased in size, power, and precision, but the essential features of their design remain much the same.

Tools Used in Manufacturing.—When one turns to manufacturing, an entirely different range of tools is encountered, and different methods prevail. Here the characteristic machines are turret-lathes of the hand-operated, automatic, and single- and multi-spindle types, and the milling machine. With them will be found the stamping press, doing all kinds of work ranging from the roughest to the extremely accurate, in the case of sub-press dies; the precision grinder, the drop hammer, and the broaching machine. On nearly all of these machines the work is done with the

use of jigs, fixtures, and special cutters, which has a profound effect upon the whole working force of the plant. The functions performed by the general mechanic operating the standard tool have been segregated into those of the skilled tool-maker in the tool room and the handy man or operative running the machine. As manufactured products are usually comparatively light, the large crane bay is not needed and the building may be of the usual multi-floored mill type (see Figure 2). As the work is put through in large quantities, it is moved on trucks or specially adapted racks. Much ingenuity has been given to the subject of these trucks and they will be taken up in another volume.*

The Interchangeable System.—In its application to the metal trades, manufacturing usually implies the use of the interchangeable system of production. The essential elements of the interchangeable system are, first, the use of limit gauges, which are based on the application of the old principle that "things equal to the same thing are equal to each other." Each part manufactured must fit definite gauges, each of which contains two limits for measuring the operation to be gauged. If it comes within these limits, the piece is known to be usable; if it falls without, it is not usable and is rejected. By this means the individual judgment of the workman as to the fitting of parts is almost eliminated. The second element, so closely allied to the first as to be almost inseparable, is the use of jigs, fixtures, and special forms of cutters. By

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* See "Handling Material in Factories," by William F. Hunt, Vol. V, Factory Management Course.

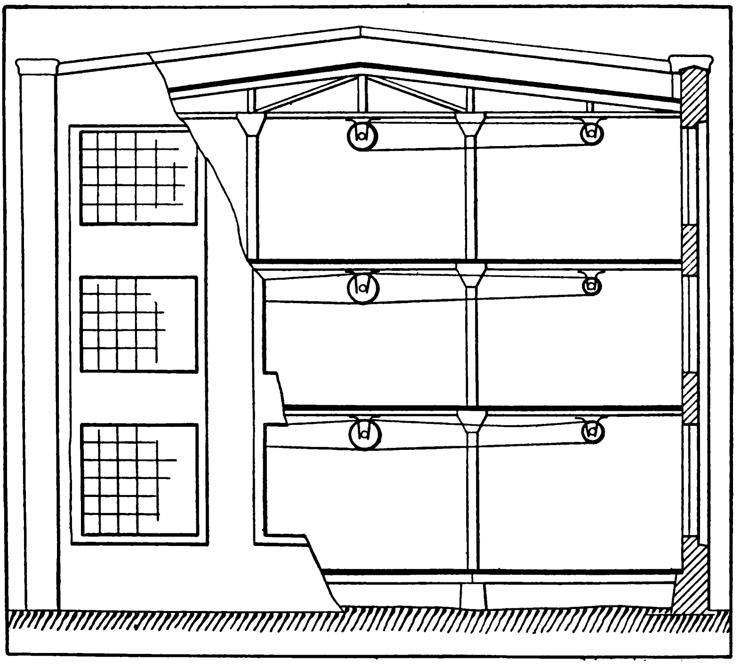

FIG. 2. TYPE OF BUILDING USED IN MANUFACTURING WORK

these the workman is also largely relieved of judgment in setting the work in the machine and in setting the tool in relation to the work.

The interchangeable system was developed by Eli Whitney a few years after the invention of the cotton gin. Few people realize that Whitney, in addition to making possible the modern cotton industry, developed commercially the interchangeable system of manufacture with its profound and far-reaching effects. It was applied by him to the manufacture of muskets for the United States Government about

1800. Simeon North, of Middletown, Conn., at almost the same time applied it to the manufacture of pistols; and in the shops of these two men it was demonstrated that work could be produced commercially upon this basis. From the gun makers, the system spread to the clock makers, and later, in turn, to the manufacture of sewing machines, typewriters, bicycles, automobiles, and the many high-grade machine-shop products which have been developed in the last two or three generations.

Many great advantages are offered by the interchangeable system. The product is much cheaper when made in large quantities, is more carefully studied out, is usually better made and more uniform. Goods may be carried in stock, and immediate deliveries are possible. Many a sale can be made of a standard article to be delivered at once from stock where a specially made article would require a long time to build. Another and equally great advantage lies in the ability to obtain repair parts; for these are obtainable both promptly and at a low cost from the repair stocks carried for this purpose. This advantage is very marked in the case of automobiles and other articles subject to breakage and wear. A standard machine of proven design for which repair parts may be obtained at conveniently located distributing centers is much more valuable to a purchaser than a special one where no repair parts are obtainable.

Certain limitations more or less offset the above great advantages, and, hence, the disadvantages should also be thoroughly understood. The invest-

ment in tools, gauges, etc., may be enormous, and becomes prohibitive when distributed over a small output. There is always the balance between the direct savings in manufacture over the building system on the one hand, and the interest charges, maintenance, etc., of the tools required by the interchangeable manufacturing system on the other hand. While the labor costs are relatively high in the building system, they may be curtailed in slack time by the discharge of workmen. Under the manufacturing system, however, the interest charges on the expensive equipment go on whether the production is large or small. The total costs, therefore, are much less flexible. It follows that the markets for a manufacturing operation must be more stable than is necessary in a building operation. The great investment in special tools, etc., based on a standard output tends to discourage minor improvements; and these special tools must show a large margin of saving to pay for discarding the old equipment and the building of the new. Standards once adopted may become so inflexible as almost to defy change.

Another danger in the interchangeable system lies in the possible obsolescence or supersedence of the product. The bicycle industry is a good example of this. At its height, this industry represented the most refined application of the interchangeable principle, and millions of dollars were invested in tools and equipment which, in a very few years, became almost valueless with the collapse of the industry.

It is evident from the elaborate preparations necessary that a long time is required to get started; and

if the preliminary work is slighted or neglected, disaster is almost certain. It requires the careful work of trained experts—new and untrained men cannot be trusted to do it. The failure of so many American manufacturers who "jumped into" the ammunition business at the outbreak of the European War, is a glaring example. Many firms, which had been building other things successfully, took contracts calling for quick deliveries and were utterly unable to fulfill their guarantees either as to quantities, time promised, or quality of work. Even the older firms, thoroughly familiar with this type of manufacture, fell down when compelled to expand their business many fold in a short time. In one of the large companies the inability to build new tools and properly to maintain both the old and the new tools, caused an actual decrease in output from that which obtained before the sudden strain was put upon them, despite an enormous expansion of their plant.

The advantages of the interchangeable system can be fully realized only when there is a large, stable and homogeneous market, educated to the use of the standardized product. Without doubt, this is one of the reasons why America has led the world in the development of the system. While the United States has a vast number of clever mechanics capable of working to the standards required, it must be borne in mind that it also offers the greatest market in the world with the greatest purchasing power. American manufacturers, operating upon the principle of interchangeable manufacture, have been notably slow in capturing the foreign market. Articles in demand in

foreign countries have not been standardized, and the American manufacturers prefer to manufacture for the large and rich home market rather than build for the diverse and scattered foreign market. It is not so much that they have been neglectful of foreign opportunity as that they have preferred to manufacture for their own market at greater profit.

Combination Methods.—Building methods will always have their place and are the only ones possible for large and unstandardized work which must be made to suit individual conditions. Great progress has been made, however, particularly in America, in the partial standardization of such work by standardizing the units employed and obtaining some diversity by the manner of assembling them. Nothing could be more diversified, for instance, than the systems of shafting and power transmission in various plants. The units which are employed have been standardized, and we have standard hangers, pulleys, shafting, etc., which are combined in different ways as local conditions require. Another example of this is the machinery for handling materials: the various elements in conveying machinery have been reduced to standards, are manufactured in lots, and carried in stock; widely diverse installations are made from these units by assembling them in framing suited to meet the conditions. This principle is carried into the design of large machinery, and many factories have standard details of design, such as standard size hubs for shafts, standard arms, and standard dimensions for various parts. This enables them to utilize the patterns, special tools,

and advantages of manufacturing in what is otherwise a varied line of output. An example of standards in dimensions is found in the distance between the centers of duplex pumps. The large manufacturers have adopted certain distances between centers, each covering a definite range of sizes, which enables them to machine the pumps on standard double-spindle lathes which finish both cylinders at once. This principle is of great importance and should be borne in mind in all plants where the output is such that it can be applied.

From the foregoing considerations it is seen that the two methods of production should be carefully considered in the design of all plant equipment and in the determination of the most desirable methods of production.

CHAPTER II

THE DRAFTING DEPARTMENT

Functions.—The functions, policies, and practice of the drafting department present too large a subject to be considered in detail here. Some only of the principles involved will be pointed out, and references cited so that special features may be studied elsewhere. A schedule of the functions is as follows:

1. Developing the design of new product which involves the making and authorizing of any alterations or improvements in the product.
2. Designing plant equipment, special tools, fixtures, and gauges, etc.
3. Establishing standards for—
   a. Product, and elementary details of the product, such as hubs, key-ways, gears, etc.;
   b. Machines and tools used in production;
   c. Supplies, such as screws, fittings, etc.
4. Furnishing complete instructions covering the above, which involves—
   a. Designs,
   b. Detail drawings,
   c. Tracings,
   d. Drawing lists and bills of material,
   e. Data-sheets,

f. Checking all of the above items (a) to (e).
g. Making blueprints.

5. Maintaining a record of work done.
6. Sometimes estimating on new work.

Functions 1 and 6 involve as supplementary work, issuing, indexing, and filing the blueprints, sketches, data-sheets, estimates, etc., and recording changes in design, pattern numbers, issues and recalls of blueprints, etc.

Design of Product.—The development of designs for experimental machines and studies of possible improvements should be done under the supervision of the chief engineer or the chief draftsman with the assistance, in the case of very large concerns, of special designers expert in a particular field. Designers should also co-operate with the shop in the testing of these machines, and make such changes as may be shown desirable in the development of the work.

Design of Plant Equipment.—In many companies much of the work covered by the second function, instead of being performed in the main drafting office, is done in independent drafting rooms scattered through the plant. Many reasons exist why this work should be under the same general control as the design of product. Drawings and designs of some sort, are involved which can be made most efficiently in the drafting department, although this work can be separated and placed into the hands of tool specialists who may or may not be in the general drafting room. It is desirable, however, that their work should "head up" to the official in charge of

the designing department. If this is done, the designs of product are much more likely to be developed with proper reference to the patterns and tools-available. Slight changes in design which will enable the utilization of existing tools are more apt to be made and the operations of manufacture to be borne in mind. In interchangeable products no new design should be considered complete until the entire scheme of manufacturing operations and of gauging each piece has been determined to the last detail.

Of necessity this work must be done in conjunction with the principal shop executives. To secure the all-round point of view necessary, a "design committee" has been found useful in some plants, which may consist of the sales manager, chief draftsman, superintendent, tool designer, and the leading men concerned in the manufacture of the proposed work, such as the foremen of the pattern shop, foundry, and machine shop. Any proposed preliminary design is gone over by this committee from the points of view of saleability, operation, construction, cost of manufacture, and so forth. This results in forestalling many of the difficulties experienced with new work. Desirable changes of design for the purpose of cost reduction are brought out, and the product designers have the advantage of the intimate experience of the men who are building and operating the tools of production.*

Standards, Drawings, and Lists.—The establishment of well-considered standards covering the de-

* See "Machine Shop Management," pp. 24-25; John H. Van Deventer. *McGraw-Hill Book Co.*

tails of design of the product, tools, and supplies is of incalculable value in lowering shop costs and investment in shop equipment.

The fourth function explains itself in the main. Drawings for complicated work should be accompanied by drawing lists locating the details on the various sheets. Such lists are of great help to the assembling department, stores department, production, cost, and purchasing departments. Formerly the compiling of bills of material was not considered a part of the work of the drafting room, but this must be done somewhere in the plant sooner or later, and it can be done much more efficiently and accurately by the draftsmen who are making the drawings.

Record of Work Done.—The fifth function—maintaining a record of the work done—is of especial importance in connection with repair work in a firm "building" machinery. Prior to 1880, drawings were considered only as instructions for the production of the work. They were made on paper, usually in pencil, and sent out into the shop. Their rough usage soon made them almost illegible and anyone who has had anything to do with repair work in an old firm knows how nearly useless these old drawings are as a record of what was originally sent out.

With the advent of tracing cloth and the art of blueprinting, it was no longer necessary to send the original drawings into the shop; and the drawings became much fuller in their information, were more carefully studied out, and became complete enough to furnish a record of the work done. This entails

several things: the first and most obvious is that the work and the drawings should conform, but only constant watchfulness will accomplish this, for there is always a tendency to make minor changes in the shop without having them properly recorded on the drawings. It is important that the work should follow the drawing exactly or, if minor changes are necessary, that they should be noted on the drawing so that the records will be correct.

Estimating.—The sixth function—estimating—depends largely upon the nature of the business. Where the prices to be quoted, as in the case of large work, are dependent upon the designs submitted, it is evident that the drawing room is involved. The degree to which it is involved and the manner of handling the work varies widely and cannot be outlined here. In some cases a committee, similar to the design committee already referred to, can be of great help in this work.

Supplementary Functions.—As indicated in the schedule, the work of the drawing room includes the issuing, indexing, and filing of blueprints, sketches, data-sheets, estimates, and other lesser items. The issuing must be done in an orderly manner to avoid leakage of information, and an accurate record must be kept to enable the recall of outstanding prints. Blueprints floating around the shop unknown to the drawing room, which are not recalled for alterations, are a fruitful source of trouble.

In order to provide ready access to the drawings and needed information, the drafting department should maintain indexes for all of the following:

Drawings, sketches, data-sheets, estimates, orders, issues of prints, etc., alterations, and sometimes, but not usually, tools and patterns. This work will be taken up more in detail later. Proper facilities should be provided for the filing of all drawings and records where they will be protected from loss or fire and will be readily accessible. The functions of issuing, indexing, filing, and recording are closely related, and much of the efficiency of a drawing room depends upon the business-like way in which it is carried on.

Personnel.—In a large drawing department there will be a chief engineer, a chief draftsman, and assistants, estimators, designers, detailers, checkers, tracers, blueprinters, and clerks who care for drawings, blueprints, orders and estimates. In small drawing rooms, two or more of these positions may be combined.

The head of the drafting room should be relieved as much as possible of routine work. He should have time to confer with the sales department, to plan new work, to supervise the activities of the drawing room, and he should also be free to spend considerable time out in the plant following work in progress. To tie him down too closely to executive routine is a serious mistake. He should be a man of high order and adequate technical training, and have an intimate knowledge of the machinery used in the plant as well as of foundry and machine shop methods. His assistants may be executives who relieve him of most of the detail, or specialists in certain fields in charge of various phases of the work, such as product, tools, etc., with designers working under their immediate supervision.

Draftsmen and detailers are always a problem in the drawing room. It is difficult to keep ambitious young men permanently at this work. College-trained men learn rapidly, but are apt to be deficient in practical information; and if they are good they soon want to move on to other work. In general, shop-trained men, who have partially educated themselves through night work, etc., are more stable and often more satisfactory. Some plants employ women for tracing and detailing. They are admirably adapted for this work as they are careful and accurate and willing to stay at it. The typical blueprint boy is about in the class of the printer's devil, and a good one is a treasure. Here, too, there is difficulty in keeping a good boy on the job. In some cases this has been settled by utilizing a man past middle life who is glad to do the work and will not be a rover. The problem of the clerical force in the drawing room differs little from the same problem elsewhere.

Policies.—First and foremost, there should be an open-minded attitude toward ideas from any source, whether from shop and foundry foremen, from draftsmen, from the sales organization, or from competitors. A good chief will be quick to recognize and utilize ideas from any of these sources and will be generous in acknowledging the credit where it is due. A jealous or small-minded man will often close himself from every one of these sources of information and in so doing will limit his own capacity and earning power; in keeping them open and in acknowledging credit where it is due, he will invariably strengthen his own usefulness.

Patience and tact are closely allied with this. Friction is almost always latent, at least, between the shop and the drawing room. Human nature is such that the first recourse of the shop is to lay bad work at the door of the drawing room. Unless carefully guarded against this is almost certain to bring about poor team play which will eventually run into steady losses for the company. For example, one chief draftsman whom I knew was a good designer and a good executive so far as his own department was concerned, but in his relations with the shop men he became so overbearing that they would go out of their way to put him in a hole. When a drafting-room mistake was discovered in the shop, they would say nothing and machine the work exactly as drawn, in order to allow it to run into as much money as possible, knowing that the expense would be charged against an account covering bad work due to mistakes in design. A new chief draftsman, however, who was a man of tact and familiar with this situation remedied it completely. He was friendly with the shop men and his first act was to go to the various foremen and remind them that, while it was an interesting game, the firm was footing the bills. He agreed that when he found mistakes on the shop he would first take up the matter directly with the foremen, and they, in turn, agreed to report any errors in the drawings to him at once. This new man was less experienced than the first and no better designer, and yet the amount of bad work due to mistakes in the drawing room fell to almost nothing. The foreman, who usually caught these mistakes just as the work was starting, would

tuck the blueprint under his arm, trudge up to the drawing room and the trouble would be made right with a few changes on the drawing at the expense of some "jollying" from the foreman and a cigar from the chief draftsman's desk. Probably just as many, or more, mistakes were made under the new regime as under the old, but they were caught early and not allowed to run into money.

I have already stated that the processes of manufacture and the keeping down of pattern and tool expense should always be borne in mind. They should be impressed on every man in the drafting room. The draftsmen should be encouraged to spend their noon hours and such other time as may be available in following their work through the shop, not only for the educative effect upon themselves, but also because they will be able sometimes to catch things which are going wrong on work with which they are familiar.

Another important policy in drawing-room practice should be the determination of and adherence to standards. There seems to be some inherent quality in human nature which tempts men to depart from standards on the slightest excuse, especially in small details, and unless watched continually the number of hand-wheels, gears, and other units creeps up—and with it shop expense.

There should be a systematic use of experience to preclude unnecessary repetition of work. Hardly a machine or class of machines exists in which certain units do not recur again and again. Unless prevented, these units are re-designed continually, according to the whim or inspiration of the moment; and the re-

sult is a variety of patterns, castings, and tools which could be greatly reduced by forethought and standardization. The advantages of studying these units as a class are that interchangeability is increased; investment in patterns, castings, and tools is minimized; assembling work is facilitated, and quicker deliveries are made possible.* This work may take the form of data-sheets covering standard details of design, standard tools, and methods of manufacture which will be available for the entire drafting room and for subsequent work.

The work of the department should be planned out and scheduled ahead as far as possible. Bulletin boards, similar to those in a modern planning department, covering work in hand, work ready to take up, and work ahead, are perfectly applicable to the drafting room. In fact, they can be applied there with as great advantage and with very much less trouble than in any other part of the plant.

All calculations and sketches should be kept. Many drafting rooms do not allow the use of pads or loose pieces of paper but issue numbered books to the draftsmen in which they do all such work. These books are useful in checking mistakes in design, and are the best kind of evidence in patent litigation.

As soon as a drafting room reaches any size, the principle of the division of labor should be introduced, and the work of detailing and tracing separated from that of designing. This keeps the highly paid men on the skilled work. Only the highest

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* See "Machine Shop Management," pp. 20-27; John H. Van Deventer. *McGraw-Hill Book Co.*

standard of what constitutes a working drawing should be tolerated. It should give complete instructions from the designer to the workman—there is no middle ground. It should be positive, thoroughly definite, clear, and self-sufficient.

Practice.—The practice of the drawing room as to sizes of drawings, style of dimensioning, sectioning, etc., should be standardized and, in the form of data-sheets, put into the hands of every draftsman and tracer when he enters the drawing room, and strict adherence to the standards should be required. Various codes of practice have been published, one of which has been prepared by the American Society of Mechanical Engineers.*

There is an increasing tendency in making detail drawings to show only one piece on each sheet. This is highly commendable, for it facilitates work in the order and production departments and also in the shop. It can be carried too far, however, but should be considered and the principle adopted as far as feasible. Many drawing rooms specify the limits of accuracy, style of finish, allowance for finish on patterns, and so on. This, too, can be carried to extremes, but the practice is sound and should be given careful attention.

For convenience in filing, a standard location and style of title should be insisted upon; and the information contained in the title should conform in size and emphasis to its relative importance. If the filing

* "Machinery's Reference Series," Numbers 2 and 33, give a very full set of instructions and rules covering many points in drawing room practice—too long to include here but well worth consulting. See also Van Deventer: "Machine Shop Management," Section II.

system is based on numbers, the number should be most conspicuous. A title should contain the following information:

Name of Company.
Name of machine.
Name of parts shown.
Number of drawing.
Number of order............First used for...........
Scale.
Designed by.................. Date...................
Traced by.................. " ....
Checked by.................. " ....
Approved by.................. " ....

Tools Available.—Lists of tools available for work, with such dimensions as concern the drafting room, (such as ranges of sizes, etc.) and lists of standard screws, bolts, and other supplies, may be included in the data-sheets already referred to and are a great help in standardizing the shop practice.

Checking.—It is often desirable that all designs should be checked twice; once before the drawing is traced to discover any mistakes in design, and again after the tracing is finished to make sure that dimensions and other details are correctly copied. Many firms, however, check their work only once—after the tracing has been completed. In either case it should be done in a systematic way and the drawing examined for:

1. General design, strength, material, method of manufacture.
2. Dimensions;—their accuracy, sufficiency and arrangement.

3. Finish and finish marks.
4. Patterns and pattern numbers.
5. Molding and foundry work.
6. Comparison with bill of materials.
7. Comparison with list of stock parts, tools, etc.
8. Notes.

Blueprints.—Blueprints should be issued only with the shop orders or upon signed requisitions from the proper persons, and record should be made of each issuance, giving date and to whom issued. This record is necessary for the recall of prints in making alterations. Prints that are standard and subjected to considerable use should be mounted on heavy cardboard, or other material, and varnished or made waterproof. In some cases it is desirable to bind sets of prints together into books for use in assembling and erecting.

Filing.—Generally, drawings and tracings are filed in flat drawers which preferably are made of sheet metal and located in a fireproof vault opening into the drawing room. Rolling the tracings and drawings cannot be too greatly condemned, for it is difficult to find the right roll and they are troublesome to use when unrolled. If possible only one size of drawing should be filed in one drawer. When large and small drawings are filed together indiscriminately, the small ones are difficult to find as they are apt to get into the back of the drawer and sometimes get lost behind it. A guard across the top at the back of the drawer is a help in lessening this last trouble.

Changes and Alterations.—No deviation from the drawings should be allowed without formal authorization from the drawing room. This is absolutely essential for the maintenance of an accurate record of work done. If any changes or improvements are made, the drawing room should recall outstanding prints and substitute new or corrected ones. Record should be made, either upon the drawing itself or elsewhere, of the serial numbers of the machines for which the drawing was used, the date when it ceased to be standard, the drawing by which it was superseded, and the first machine on which the new drawing was used. This record is invaluable in caring for repairs.*

In making changes and alterations, it is well to follow a definite procedure to make sure of covering the various items which require attention. The following list covers most of them:

1. General assembly tracings.
2. Detail tracings.
3. Drawing lists.
4. All blueprints outstanding should be recalled and replaced with correct ones.
5. Patterns involved.
6. Special tools involved.
7. Disposition of stock on hand, if any.
8. Necessary records of the change.

Equipment.—The general practice in the past has been to use drawing tables large enough for a loose

* For procedure in changes in alterations, see Van Deventer, "Machine Shop Management," pp. 35-37; also "Machinery Reference Series," Nos. 2 and 33.

drawing board, with room at the side for reference drawings and other papers. In many places the vertical board is preferred and for large drawings it is unquestionably more convenient, but when it is used tables should be provided for holding any reference drawings. In either case parallel rulers will be found preferable to T-squares; in large work their use is almost universal. The "Universal" drafting machine," combining a parallel motion, protractor, and scales, is a convenient and time-saving device, well adapted to many forms of drafting work.

Few modern drafting rooms rely upon sun printing for making their blueprints. A number of electric machines are on the market which make prints rapidly, day or night, rain or shine. Many of them combine washing and even drying with the printing process, and their convenience and availability at all times make them preferable in every way to the old sun-printing frames wherever there is any large amount of blueprinting to be done. Such a machine is shown in Figure 3.

Two new machines are now available, the "Photostat" and the "Rectigraph," which will photograph any kind of record—a drawing, order, printed page—in a few moments' time and at moderate cost. While the machines are expensive, they can be used in a great many ways for saving time and in avoiding errors in copying. Their possibilities and availability should be considered in every large drafting room.

Location of the Drafting Room.—Generally speaking, the drafting room should be convenient to the

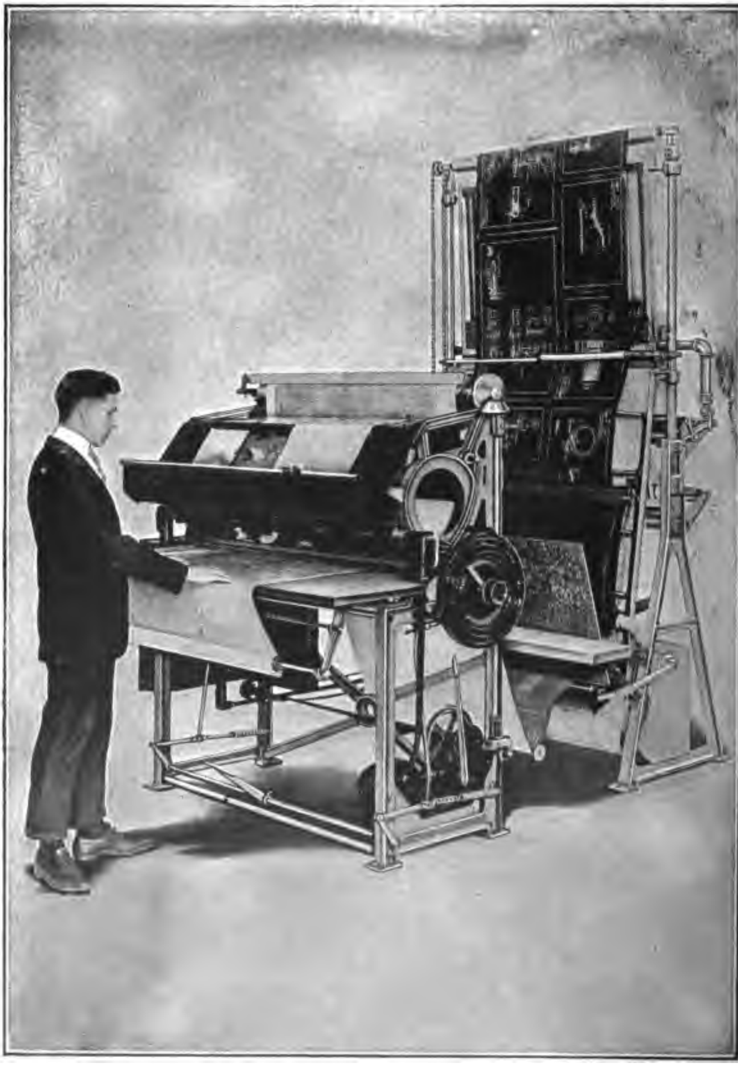


FIG. 3. CONTINUOUS ELECTRIC BLUE PRINTING MACHINE
C. F. Pease Company.

office, pattern shop, tool room, and, if possible, centrally located with respect to the shop. It should be roomy, well ventilated, and have white or light-toned walls. The best possible lighting is the cheapest—a north light for the daytime, and an artificial light so arranged as to avoid eye strain and eliminate shadows for evening work. The work calls for close use of the eyes, and few realize the lowering of efficiency in a drafting room where the light is poor. The expenditure represented by the difference between the poorest lighting and the best obtainable is soon paid for.*

* Clewell: "Factory Lighting," Chap. VI, on Drafting Room Lighting.

CHAPTER III

THE PATTERN SHOP

Function and Location.—The functions of the pattern shop are to make, maintain, and store patterns and core boxes, and to keep the pattern records. As patterns are usually of wood, this involves a woodworking shop with the necessary benches and machinery. Metal patterns may be used in manufacturing plants where there is repetition work and machine molding; and this would involve, in addition, metal working equipment adapted to the manufacture of iron patterns, stripping plates, and such articles. The pattern shop is in frequent communication with the foundry and with the drafting room. It should be located, therefore, conveniently with respect to these two departments, preferably between the two.

Balance of Pattern Makers' and Molders' Time.—The cost of a pattern is distributed over all the castings made from it, and when great numbers of castings are made, may become almost negligible; but the molder's time enters into the cost of every mold and increases directly with the number of molds made. If but one casting is wanted, it pays to make the cheapest pattern possible and let the molder spend more time on his work. Where the pattern is to be used for many castings, it will pay to spend much more time upon it, if thereby the molding cost

can be cut down, for this saving will appear in every casting made. For illustration, let us assume the pattern maker's and molder's time each at $4 per day, and compare the total cost in making one casting as against ten castings.

	One casting	Ten castings
Pattern maker's time, 1 day........	$4.00	$4.00
Molder's time, ½ day to each casting.	2.00	20.00
Total combined cost............	$6.00	$24.00
Combined cost per casting......	6.00	2.40

Suppose now the pattern maker to spend three days making a better type of pattern which will enable the molder to make molds at the rate of ten per day. We then have:

	One casting	Ten castings
Pattern maker's time, 3 days.......	$12.00	$12.00
Molder's time, 1-10 day to each casting	.40	4.00
Total combined cost............	$12.40	$16.00
Combined cost per casting.......	12.40	1.60

A comparison of the first columns shows clearly that for one casting it will pay to make a cheap pattern and let the molder spend a half day on the mold. For ten castings it will be cheaper to let the pattern maker spend several days in making a better pattern to gain the saving in the molder's time. If similar calculations are made on the basis of two, three, and four castings, it will be found that the cheap pattern is still the more economical. At five castings the combined cost per casting is the same. Beyond that number the advantage is increasingly in favor of the more expensive type of pattern.

In the above example, both the wage rates and the molder's and pattern maker's time have been assumed arbitrarily, but the principle is the same in any case. Each pattern is a separate problem. Sometimes the simplest, at other times the most expensive, type will be cheapest. From this principle it is obvious that there should be constant and closest co-operation between foundry and pattern-shop foremen to determine the kind of patterns to be made.

The pattern shop and the drawing room must also work together to utilize existing patterns as far as possible and to reduce the number of patterns by the use of loose pieces for making right- and left-hand castings, etc.

The facilities for storing patterns should be adequate, accessible, fireproof, and capable of expansion. All patterns should be indexed and records kept showing their location, condition, etc.

Pattern making constitutes a highly skilled trade and is too intricate to be dealt with in detail here. Those who would desire even a general knowledge of it are referred to some of the elementary books on the subject. Here, as in the case of the drafting room, we will take up only some of the general features.

Types of Patterns.—The simplest form of pattern is the one-piece pattern used only for small castings. Its sole merit is that of being cheap. It throws a great deal of work on the molder, but it is often used for simple work where only one casting or but a few castings are required.

Where castings are required in moderate numbers,

the pattern would be split, and the two portions doweled together, one half forming the drag impression, the other the cope.* This simplifies the work of molding, and, hence, this type is most commonly employed for medium sized work. The parting of the mold generally coincides with the parting of the pattern. After the mold is formed, the cope is lifted off the drag, the two halves of the pattern removed and put together again for use on the next mold.

When the principal surfaces of a casting are plane surfaces or those of translation, a skeleton pattern is used which gives only the outline of the casting. This is set in the mold, and straight-edges or "strike boards" are slid along the skeleton to generate the intermediate surfaces. This type is very useful for large work, as the saving in the cost of pattern work and lumber more than offsets the extra labor of the molder.

The same principle may be applied to surfaces of revolution, such as cylinders, wheels, gears, and so on. A "strike" having the outline of the surface to be generated is mounted at the desired radius upon an arm swinging on a spindle and used to generate the surface of the mold. In making molds for gear wheels, an accurate pattern of one tooth is mounted on a spindle and revolved at the proper pitch radius from position to position. This principle is embodied, with the relative motions reversed, in the Mesta molding machine. The mold is mounted on the circular table of a machine not unlike a boring mill; a segment of the pattern carrying the tooth is mounted

* For definitions of drag and cope, see Chapter V, page 56.

on a cross rail, and the mold revolves under it from position to position until all the teeth are molded. In this way a very accurate mold may be made. In sweeps, the strike board may also be made to advance uniformly along the axis as it is rotated. This generates a spiral surface and is used for molding the spiral grooves in rope sheaves and sometimes for the working faces of screw propellers.

Gated Patterns.—Where small castings are made in great quantity, it is best to make several impressions in one mold. This involves the use of gated patterns,—the patterns for a number of pieces being mounted upon a single plate and molded simultaneously. The patterns are connected by a common gate which leads the molten metal from a single pouring opening to the various impressions. Gated patterns, which are very generally used on molding machines, may be made of wood, but they are more often made of cast iron or brass. Two general types of gated machine patterns are used: in the first, the patterns are permanently secured to the pattern plate; the flask is placed over the pattern, filled with facing and sand which is rammed, squeezed, or jarred, and the mold is then lifted clear of the patterns. In the second — the stripping-plate type — the patterns are mounted on a separate plate. After the mold is made, the patterns are withdrawn downward clear of the mold through a "stripping plate" which fits the patterns closely at the parting line and supports the sand during the act of withdrawal. This type requires little or no draft, and the molding work is fast. Where cope and drag impressions are necessary, it is

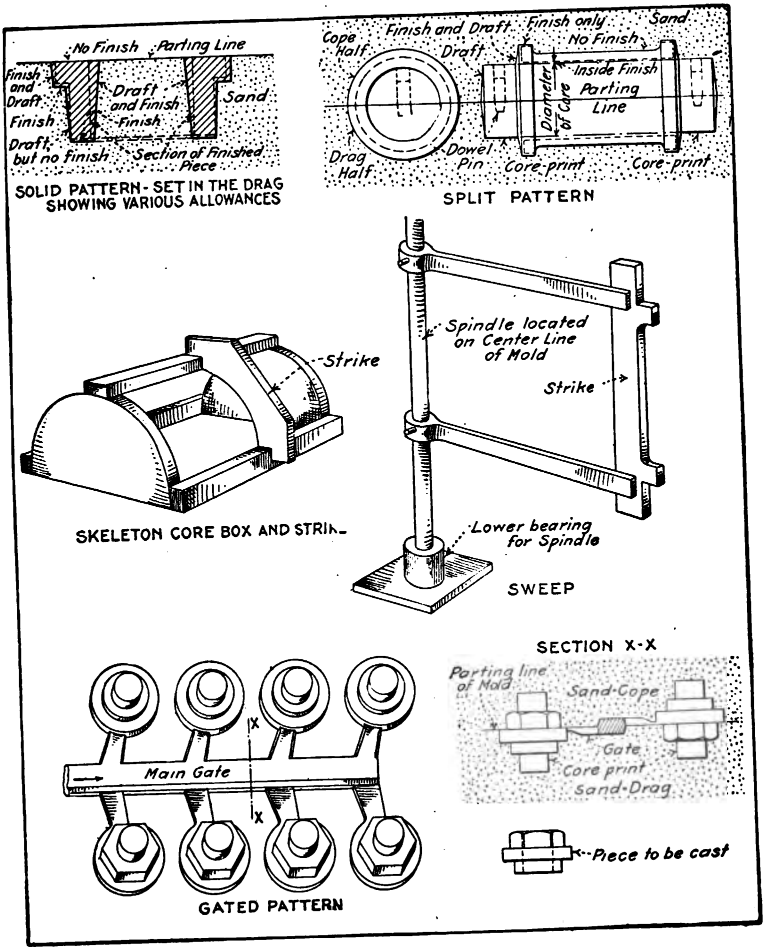


FIG. 4. TYPES OF PATTERNS

desirable to arrange them on the same pattern plate on opposite sides of a line of symmetry, a cope impression on one half matching a drag impression on the other half. If this is done, the cope and drag of the mold will be the same. This saves making two plates, one for cope and one for drag impressions, and lessens the amount of work in both pattern shop and molding floor. Figure 4 shows a simple gated pattern, not mounted on a plate. The principle, however, is the same as that just described.

Patterns for large work, such as that done in loam foundries, are built up of many pieces and are often very complicated. Parts of the pattern—for instance, large flat surfaces—may be left open and the mold finished with a strike board; while flanges, bosses, etc., may be made in full and carried on the frame of the pattern. Arms and other projections may be in loose pieces, and the mold may be made in flasks having two or even more parting lines.

Pattern Material.—The prevailing material for patterns is wood—air seasoned and perfectly dry. Patterns of a permanent nature and of fair size should be built up of several thicknesses, with the grain reversed to neutralize the tendency to warp. White pine is most generally used as it is straight grained, is free from knots, works easily, and takes varnish well. For molding large quantities of small castings mahogany is used. It is much stronger and harder than pine, works less easily, but it stands moisture as well or better, and has little tendency to warp. Bay wood, a species of mahogany, but lighter and softer, is

sometimes used, and, for special purposes, cherry, black walnut, maple, and birch.

Allowances.—Certain allowances are made in patterns that give them a shape slightly different from the casting to be produced from them. Foundry metals shrink in cooling, and if castings are desired of a certain size, the patterns must be made larger by an amount sufficient to allow for this shrinkage. The allowance for grey iron is about an eighth of an inch to a foot; for malleable iron and brass, about three-sixteenths inch to a foot, and for cast steel and aluminum, which have a heavy shrinkage, as high as one-fourth inch to a foot. For various reasons this shrinkage is not always equal in all directions and this discrepancy must be cared for by varying the shrinkage allowance.

Another allowance which must be made in patterns is that for draft. It is practically impossible to lift the pattern from the mold without breaking the corners if the sides of the pattern are at right angles to the parting line. To avoid this, they are made on a slight taper which should be greater on an interior surface than for an exterior one, as shown in Figure 4.

Wherever the surfaces of the casting are to be machined, there must be additional metal added which is cut away in the machining operations. On small and simple castings this may be as little as 1-16 inch. In large castings, ⅛ or ¼ inch must be allowed.

Before the patterns are withdrawn from the mold they are often rapped by the molder to free them from the sand. This enlarges the mold slightly and

is sometimes taken into account in the dimensions of the pattern. Another advantage of the stripping-plate type of pattern is that it does away with the difficulties introduced by rapping as well as the necessity for draft, which was previously mentioned on page 34.

Warping and Splitting.—The principal cause of warping in patterns is moisture in the wood. For this reason the lumber used should be thoroughly seasoned and the pattern may be built up as already explained. The second cause of warping is moisture in the mold. To provide against this, patterns are heavily varnished and painted to keep the moisture out. Splitting is usually caused by rapping the pattern in the mold. Suitable rapping plates will obviate trouble from this source.

Fillets.—All corners should be rounded whenever possible. The corners look better, the pattern makes a cleaner mold, the molten metal does not wash away the sand, and the castings are much stronger. For internal corners in the pattern wood strips may be used, or leather strips—which come especially cut for this purpose—can be secured in the corner with tacks and glue. These leather strips are widely used, as they can be run around curves and irregular places. For cheap patterns intended for temporary use, the fillets may be made of linseed-oil putty.

Core Prints.—The supports for all cores should be large and well placed. The best practice in modern shops is to standardize the sizes of core prints wherever possible. This lessens the cost both in the pattern shop and in the core room.

Marking and Painting.—All patterns should be painted, preferably in two colors—the pattern in black, and the core prints, core parts, and boxes in red. All the loose pieces of both the patterns and core boxes should be so marked as to identify them with the pattern to which they belong.

Pattern Storage.—The pattern storage should be guarded against fire with the greatest care. It should be so located that it may not be in danger of catching fire from sparks from the foundry or from other buildings; and it should be protected from fire from within by the best possible fire-fighting apparatus. Hydrants and hose should be available and, if possible, a sprinkler system. The air should be kept warm and dry to avoid the splitting and warping of the patterns. Obviously, related patterns and their parts should be together. The patterns should not be piled at random; they should be stored according to some well-thought-out, orderly system, with the smaller ones on shelves arranged in aisles. Shelves for patterns should be adjustable, and the whole scheme of arrangement capable of expansion, as the number of patterns to be stored increases steadily and may become very great—some pattern storages in this country house more than a million patterns. Every pattern should have a definite place and should be identified with that place in the pattern index.

Index System.—A card index should cover all patterns in storage, and each card should contain full 'nformation necessary to locate and describe the pattern. On each card the following data should be shown:

Pattern number
Size and name of the part
Size and name of the machine
Drawing number
Order number
Date made
Location in loft, section, aisle, and shelf
Number of pieces in pattern
Number of pieces in core box
Record of alterations

A record of the castings made from pattern and the order numbers covering them may be given in suitable space on the backs of the cards.

Records.—Systematic records, usually by a card index, should be maintained of the issuing of patterns, as follows:

Patterns sent to foundry and core room.

Patterns sent to outside foundries.

Patterns sent to pattern shop for repairs.

In some storerooms provision is made for cards on the shelves, which will give the location of the patterns when they are out of storage. This is not always necessary, as the above office records should contain such information.

CHAPTER IV

FOUNDRY METALS AND FOUNDRY BUILDINGS

Metals.—The principal metals which form the product of foundries are grey iron, chilled iron, white or malleable iron, cast steel, brass and bronze alloys, and aluminum.

Grey Iron.—Grey iron is used for machinery castings. Its ultimate tensile strength will run from 20,000 to 25,000 pounds per square inch. But for these castings, soundness and ease of machining are of more importance than great strength. A great many mixtures of grey iron are used for special purposes. The chemical composition and strength are more or less influenced by the size of the product, and special physical properties are sometimes required. Cylinder and pump castings, for example, should be dense, close grained and free from shrinkage spots, and as hard as is consistent with machining in order to wear slowly to a high polish. Castings for dynamo frames are made of very soft iron to prevent the retention of residual magnetism.

Stoves, radiators, and ornamental castings, on the other hand, are made from iron with high percentages of phosphorous and silicon. This composition is very fluid in the molten state, flows freely in thin sections, and fills the finest lines of the mold: it is brittle and

will not machine well, but these castings are not intended to be machined. "Semi-steel" is made by adding from 10 to 40 per cent of steel scrap, giving a strong iron which can be machined, although with some difficulty. Gun iron is the most reliable and highest grade of grey iron made: It is melted in air furnaces and used for small engine cylinders, fine finishing rolls, and similar precise work.

Chilled Iron.—When grey iron is poured and allowed to cool slowly, the casting is soft and the carbon content is largely in the free or graphitic state. But if, instead, the pour is cooled suddenly, the surface to a depth of one-half inch to an inch becomes exceedingly hard and crystalline, and the carbon remains chemically combined with the iron. This property is utilized in the making of chilled-iron castings. In making the castings the metal is poured into iron molds or, more generally, into sand molds in which iron castings covering the part to be hardened have been set. The metal pieces used for this purpose, "chills," as they are called, may be solid or, if the mold is large, hollow to permit the passage of steam for drying and of water for the rapid cooling of the pour.

The process permits castings, known as chilled-iron castings, to be made, of which some parts will have the composition and machining qualities of ordinary grey iron, while the parts that have come in contact with the "chill" may be almost glass hard. The metal used for the process is usually high grade, having small contraction, and being melted in air furnaces. Car wheels and iron rolls furnish examples

of such work, and some foundries make this their specialty.

Malleable Iron.—Malleable or white iron has a strength between that of grey iron and cast steel, or about 30,000 to 35,000 pounds ultimate tensile strength to the square inch. While it cannot be forged, it can be bent and twisted, and resists shocks well. It is cheaper than cast steel and better adapted for small work. When cast it is known as "white iron" and is hard, crystalline, and very brittle. The cast metal is annealed by heating in scale or iron oxide at a temperature of about 1350 degrees Fahrenheit for several days and then cooled very slowly. This process burns out some of the carbon and converts the rest from the combined to the graphitic state. The product is dark grey and is then known as "malleable iron."

Cast Steel.—Cast steel is classified by the way it is melted as electric furnace, crucible, acid open-hearth, basic open-hearth, and bessemer. The electric furnace and crucible methods are used only for very high-grade products and small castings. Open-hearth steel is the cheapest and most used. It is strong and malleable, its ultimate tensile strength running above 60,000 pounds per square inch. It requires a high heat for melting, about 3300 degrees F., is poured only from bull ladles and is sluggish in pouring, takes the mold poorly, has a shrinkage nearly double that of cast iron and should be annealed to relieve the castings of shrinkage strains. Heavy risers are required to take care of the shrinkage. Because of these and the rough character of the product, steel found-

ries are still confined to work of medium and large sizes. Cast steel is supplanting large forgings because it is cheaper, and, in general, more reliable, especially where the forgings are built up by welding, such as locomotive and ship frames. The art of casting steel is developing rapidly and it is gradually being utilized for smaller and smaller work.

Alloys.—The principal metals used in the various alloys are:

a. Copper: A tough, malleable, ductile, non-corrosive metal which is a good conductor of electricity and casts poorly. It is quoted commercially as lake, electrolitic, and casting copper.

b. Tin: A crystalline metal, malleable at ordinary temperatures.

c. Zinc: A hard and weak metal, which oxidizes slowly. In the form of sheets it is known as zinc; in ingots as spelter.

d. Lead: A very malleable, soft, and weak metal; little used except in bearing metals, where it is important.

e. Phosphorus: An element never used in the pure state; ordinarily it is used in the form of phosphor-tin which carries about 5 per cent phosphorus. Phosphor-bronze mixtures contain from 90 to 96 per cent of copper, 10 to about 3¾ per cent tin, and about ¼ per cent of phosphorus. They are tough, very strong, and resist corrosion.

f. Aluminum: (See below.)

There are a great number of foundry alloys differing widely in composition and physical properties. The two principal alloys are brass, which is composed of copper, zinc, and tin; and bronze, which is composed mainly of copper and tin. Even these two are subject to wide variation according to the purpose for which they are intended.

Brass foundries naturally deal with smaller castings than iron foundries, for the material handled is much more valuable; but the number of castings is often very large, hence machine molding is common. The brass used in small castings is tough, non-corrosive, and a good "body" for plating. Owing to the wide variety of mixtures used, the metal is melted in small quantities in crucibles, or by oil or gas furnaces.

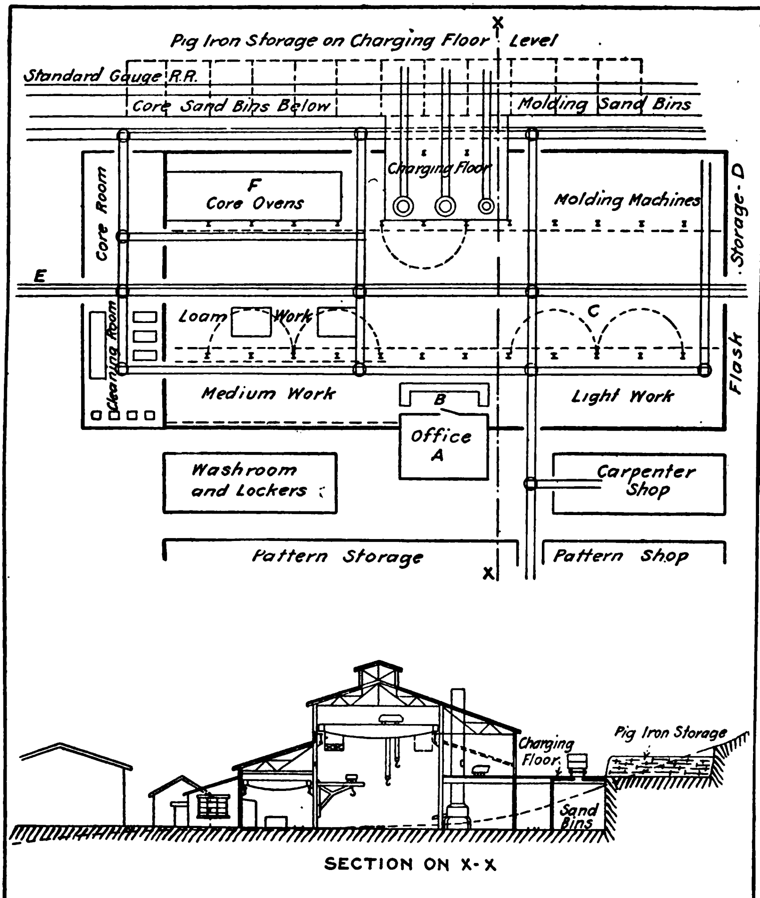
Aluminum foundries are of increasing importance, particularly in the manufacture of automobile parts. In general, their characteristics follow those of brass foundries. Aluminum is soft, very ductile, and non-corrosive. It is a good conductor of electricity, has a heavy shrinkage, and is inclined to be porous. Its most characteristic quality is its extreme lightness; but weight for weight its tensile strength is exceeded only by the best cast steel.

Foundry Buildings and Equipment.—In a foundry the following processes must be provided for: molding, core-making, melting, pouring, and cleaning. These involve the storage and transportation of flasks, sand, coke, pig iron, molten metal, and of rough and finished castings.

Modern foundry buildings are usually of steel frame construction with monitor and side bays, the outer walls being filled in with concrete or brick. The main building should be of good height, and there should be ample provision for light and air. The ever-present smoke and dust soon cover the windows, hence, more than the usual allowance of window area should be provided to give sufficient light. The lighting, so far

as possible, should come from the side walls, as side windows are easier to clean and will stay clean longer. The best method of heating and ventilating is the indirect fan system, where fresh air is drawn in from the outside, heated, if necessary, and delivered to all portions of the building. Ample provision should be made for the escape of gases and smoke through the clear story at the top of the roof. The floor should consist of molding sand, the depth varying with the class of work to be done. A foundation of clay, well rolled down, will help greatly in keeping the molding floor in good condition and prevents the moisture from draining into the ground. Figures 5 and 6 give a plan and cross section of a foundry for general work. The arrangement will vary widely with different cases, but the one shown will illustrate the relation of the various processes.

The office, A, should be centrally located, with a good view of the main floor and partitioned off from it by glass to render it as free as possible from dust. It should be on the side nearest the pattern shop. A temporary storage equipped with low tables and shelves for patterns, B, is provided outside of the office. Here the foreman and his assistants can check the patterns as they come in and hold them for issuance to the molders. The heavier work will be molded on the floor of the main bay where it can be served by the overhead cranes, which are necessary for handling the large flasks, cores, and pouring ladles, and for lifting the castings from the mold. The large green-sand castings may be made at one end, C, nearest to the flask storage, D, which is in



FIGS. 5 AND 6. PLAN AND SECTION OF A GRAY IRON FOUNDRY

the yard outside. Flasks for the dry-sand and loam molds may be brought in from the opposite end, but as the loam work is the heaviest it should be so located as to involve the least transportation. The loam and dry-sand core work should be located conveniently with respect to the ovens, F, used for drying the cores and molds. The core shop may be in a separate building or, if under the same roof, should also be near the ovens.

Light floor work and machine molding may be located in the side bays where the light is good and the transportation problem is less important. The molding machines may be placed to advantage on the side nearest the sand storage to permit the use of overhead belt or bucket conveyors and chutes for delivering the sand directly to the flasks on the machines. The sand mixing should be located between the sand bins and the main floor. Air-operated sifters and mixers facilitate this work. The cupolas should be centrally located, with the bull ladles under the main crane. In large foundries there will be two or more cupolas, in order that different mixtures may be melted simultaneously. Small cupolas are often installed near the floor for light work to serve that floor alone. Blowers should be placed near the cupolas to avoid long wind pipes.

The cleaning department should be located either at the end of the foundry or outside. Sufficient space should be provided to pile the castings as they are brought from the floor and to give sufficient room for men to work. Small castings will be cleaned in tumbling barrels, or in pickling tubs, or by the use of

emery wheels. As this work is of necessity very dirty and involves fumes, it is well to have it in a separate building or room. Very large castings are usually cleaned on the main floor, and air chipping hammers are indispensable in this work. In fact, compressed air has become the handy man of the foundry; it is distributed about the foundry in pipes and flexible hose at about 80 pounds pressure, and is used for operating the molding machines, for blowing out the molds and for lifting the small flask molds and cores.

Storage.—The pig iron is stored outside—in the illustration it is on an upper level, even with the charging room floor. The topography here allows the use of a standard-gauge railroad spur outside and up to this level, which permits the unloading of the pig iron and coke on that level and the delivery of the sand by gravity into the bins, M, underneath the track on the level of the main floor where it will be used.

Transportation.—The main bay is provided with traveling cranes which are heavy enough to handle the largest flasks, ladles, and castings. Lighter traveling cranes may be installed under the bays for similar service on medium-sized work, and it is desirable to have jib cranes in addition. The traveling cranes should be used for general transportation from one part of the building to another; the jib cranes for local work. The setting of heavy cores and molds frequently takes considerable time, and the overhead crane is too valuable a machine to be tied up with this work when other parts of the foundry may be need-

ing its service. The best practice, therefore, provides a combination of jib and traveling crane service for this heavy work; while for light work, overhead tracks and trolleys combined with air hoists are very efficient. The overhead trolley leaves the floor free from obstructions and clear for setting out the molds. Standard-gauge railway tracks should enter the main foundry floor in order that the overhead cranes may load the larger castings from the floor directly upon railway cars for shipment to other departments or to outside plants. Wherever possible, the molten iron should be distributed by cranes or overhead trolleys; the use of industrial railways for this purpose is inefficient and dangerous. Industrial railway tracks will provide for bringing in the flasks, patterns, and sand and for transporting patterns and cores. Turntables are preferable to curves on industrial railways inside of a building, for they are more economical of space and the nuisance caused by cars jumping the tracks on sharp curves is avoided. However, the subject of transportation is handled elsewhere in this series, and the reader is advised to consult that volume for full information.*

Clean, sanitary lockers and washrooms are a part of modern foundry equipment. Foundry work at best is dirty; but foundry workmen are as self-respecting as any others, and haphazard washing facilities and dirty clothes hanging along the walls are neither sanitary nor conducive of self respect.

In the arrangement shown in Figure 5, the patterns

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* See "Handling Material in Factories," by Wm. F. Hunt. Vol. V, Factory Management Course.

come in from one side of the foundry, the supplies from the other, and the flasks from one end, E. The general movement of material is from right to left and out on the railway tracks at the left end. The foundry shown is for general work suitable for handling light and heavy grey-iron castings. In brass foundries where the work is light and in steel foundries where it is heavy, there would naturally be a somewhat different arrangement, although many of the features would be similar.

CHAPTER V

FOUNDRY MOLDING METHODS

Materials.—Foundry molding is divided into four well recognized branches—green sand work, dry sand work, loam work, and core work. The first three give their names to corresponding types of foundries, according to the type of molding which prevails. Core work is common to all three.

In green sand foundries the molds may be poured as soon as they are made, and because of the quickness and cheapness of the process this is the commonest method of making castings.

In dry sand molding a core sand mixture is used next to the pattern and the mold is baked after the removal of the pattern. The baking drives off all moisture and leaves a hard, clean surface. It is used where the rush or bulk of metal would spoil a green sand mold.

Loam work consists of building up a mold of brick on which a facing of mortar is placed. The correct form is sometimes given to the mold by a full pattern, more often by a skeleton pattern or a sweep, after which the entire mold is baked. Loam work is used for heavy castings where the pieces are few, and calls for more skill than any other form of molding.

The principal supplies used in molding are sands,

loam, facings, fire clay, parting dust, and core binders.

Molding Sands.—Good molding sand may be light, medium or heavy. It must be porous enough to allow the escape of air, steam, and the gases generated in pouring, and at the same time compact enough to hold its shape and withstand the rush of metal. It must be refractory to withstand the high temperatures, and it must not have any chemical reaction with the molten metal. It must be readily removed from the casting and leave a clean, smooth surface. The selection of proper sand is of vital importance; it is largely a matter of experience and one of the essential elements in a foundryman's skill.

The most important element in the sand is silica, which forms about 85 per cent and gives the requisite heat-resisting quality. If the percentage of silica runs too high, the sand will crack in drying and the mold will not pack and will not be impervious to the metal. Alumina, or clay, the other important element, comprises about 8 or 9 per cent of the composition; it furnishes the bonding quality and renders the sand plastic and cohesive. Magnesia also acts as a bond and if too much is used, the necessary porosity will be lost. The lime and metallic oxides that are present in most sands are harmful. The metallic oxides should not exceed 4 per cent nor the lime 1 per cent. Sand used in brass foundries runs about 10 per cent lower in silica and is higher in iron oxide. For small castings, as there is less need of venting, a fine-grained sand is used which contains more alumina than the coarser-grained sand required for heavy

castings; since the heat is less the sand need not be so refractory and may contain less silica.

Free sands contain about 98 per cent of silica and have less than 2 per cent of alumina. There are two kinds, river and beach sand. River sand is made up of sharp, chipped grains and makes a very strong core. Beach sand is smooth grained and used only for small cores and for parting sand.

Loam.—Loam is a soil composed chiefly of silica sand, clay, and carbonate of lime, with some oxide of iron and magnesia, and decayed animal and vegetable matter. Next to molding sand it is the most important material used in the foundry. It parts with its water at red heat, and at the temperature of molten iron the carbonate of lime will fuse and become vitrified. Black loam is a cheap variety, having strong binding properties and is used for setting the brick work in loam molds.

Facing.—Facing is usually some form of carbon such as graphite, charcoal or coke. It is used to give a smooth surface to the face of the mold and, as it burns slowly under the heat of the metal, it forms a thin film of gas between the iron and the sand, preventing the sand from burning into the casting and causing it to separte from the casting when cold. Facing should be very finely ground; it must not burn too easily, and must adhere firmly to the face of the mold so that it will not be washed away by the molten iron. Blacking, as it is called, is a mixture of facing with a clay wash or molasses water which is applied to the finished surface of a mold or core. Facing sand is a combination of molding sand and

coal dust, used next the pattern on large work. Parting sand, which may be burnt sand, charcoal, or manufactured preparations, is used between the flask and the cope. It must be absolutely non-tenacious, so that there will be no adherence between the two pieces.

Cores and Core Binders.—Cores are sand shapes which partially fill the impression in the mold and thereby form the holes or hollows in the castings. They are generally supported by extensions, known as core prints, which extend into the body of the mold. The conditions required of cores are exacting. They must be strong to resist flotation and being washed away; they must be highly refractory because they are almost completely surrounded with molten metal, and yet after the casting has cooled, it must be possible to remove them completely and easily. To accomplish these purposes they are made of free sand containing little or no alumina which would cause them to cake and make them hard to remove. The core sand is mixed with binder, a vegetable compound of ordinary wheat flour with rosin, linseed oil and molasses. When the cores are formed they have little or no strength and are too weak for use in the mold. To give the necessary strength they are heated in ovens to bake the binder and give it the strength required. When the mold is poured, the high temperature of the molten metal burns out the binder and reduces the core to a mass of loose sand which can be dug out with ease. As it takes time for the binder to burn and the gases to escape, the core retains its strength long enough for the metal

to set. Cores are frequently strengthened with iron rods, pipe, and, at times, with specially cast core irons. Where these are not sufficient, chaplets, which are small supports made in many varieties and shapes are used. It is intended that they fuse into the casting, but they are at best a necessary evil as they weaken the casting in three ways—by the introduction of a foreign metal, by the formation of porous spots about the chaplet, and sometimes by a failure to fuse. They are necessary, however, in many classes of work.

Cope and Drag.—Molds are made in flasks consisting of two or more rectangular frames of the same length and breadth, the upper one known as the cope and the lower one as the drag or nowel. When there are three parts, the middle one is known as the cheek. The frames are used to hold the sand while the impression of the pattern is being made. They are made of wood, cast iron, or pressed steel. Iron and steel flasks should be used for standard work; wooden flasks are much cheaper, but they deteriorate rapidly and must be handled with care. The copes of large flasks usually have crossbars to help in holding the sand in place. The cope and drag are made to register with each other by means of guide pins and sockets. In the ordinary type of flask the mold remains in the flask while the casting is being poured, necessitating the use of as many flasks as there are molds.

"Snap flasks" resemble ordinary flasks except for the fact that they are hinged at one corner and are provided on the diagonal corner with latches, so that

they may be opened out after the mold is formed and lifted clear of it. They are used for small work where the mold is strong enough to stand the pressure of the metal without the help of the flask. After a mold is in place on the floor, the flask is taken off and is used in making the next one. Hence, but one snap flask is required for any number of molds—a great saving in machine molding large quantities.

A "mold board" is a board the size of the flask on which the drag and pattern are placed in making the mold. A "match" is a form made of sand, oil, or plaster of Paris into which a solid pattern is inserted to its parting line, and is used as a mold board for making the cope. Sand matches are used only where a few castings are needed, while the plaster of Paris matches may be used indefinitely. Matches are made in shallow frames the size of the flask to be used, and are provided with sockets to engage the pins on the cope portion of the flask.

Small Tools.—A number of small tools are used by the molder; these include a riddle for sifting the sand into the mold; rammers of various shapes for tamping and ramming the sand about the pattern; the straight edge for striking off excess sand; and slicks, which are small, specially-shaped trowels for finishing off the surface of the mold after the pattern has been withdrawn. In addition to these there will be sprue plugs which are cylindrical pieces of wood used in making the runner through which the metal is poured; draw spikes and draw plates to help in lifting the pattern, and vent rods for making passages for the escape of gases.

Making a Mold.—The first operation of importance in making a mold is the preparation of the sand—that is, mixing the proper proportions of old and new sand and tempering the mixture. Too much new sand causes the mold to crack, as it will not vent properly; not enough causes the cutting or washing away of the mold.

Tempering is done by moistening the sand with water until a handful of it can be squeezed into a firm, egg-shaped lump that will break cleanly without crumbling. Too little tempering gives a weak mold; too much tempering produces an excess of gases.

The next operation is the ramming of the drag and then the cope, that is, sand is shoveled into the flask and is packed around the pattern. If the sand is rammed too hard, blow-holes may result because the natural vents or air cavities are filled up; and if it is not rammed hard enough it will sink under the weight of the metal or be washed away. The joint of the mold where the two parts come together should be rammed hard, as it is exposed to handling. In general, the mold should be as soft as possible and still retain its shape. Gaggers, which are L-shaped pieces of iron, may be set in the mold, when necessary, to give it the requisite strength.

When the mold is formed, it is vented. This is accomplished by opening up passages for the escape of gas, air and steam. If this is not done, the mold may explode, or some parts may not be filled with iron on account of the pocketing of gas which cannot get away. New sand needs a good deal of venting. Af-

ter venting the mold, an opening is formed through which the metal is to enter the mold. This opening has three parts, known as the pouring basin, the runner or sprue, and the gate. Making it properly requires skillful handling and its neglect is responsible for many bad castings. The gates should be large enough to fill the whole mold quickly, and should be located so that the metal will rise into the mold and so that the sprues may be machined or ground off. Risers are vertical openings extending from the impression to the top of the mold; they serve a three-fold purpose, as a vent, as a skimming gate, and as a supply for additional metal to make up the shrinkage in cooling.

After the pattern is removed the mold will often need some patching, and a good molder will repair one which seems to be ruined. Patching should be done with the fingers wherever possible. The mold is then faced. Too much facing produces excessive gas and causes blow holes; too little facing results in dirty castings. After this operation, the cope or upper half of the mold is put in place upon the drag half and the mold is ready for pouring.

Dry sand molding is similar to green sand work except that core sand is used next to the pattern and is backed off by molding sand. After the mold is made it is baked or dried and is then given a coat of blacking. Dry sand molds are made in iron flasks to permit their being placed in the oven. It is necessary to vent dry sand molds also, not because there is moisture in them, but the gases from the burning facing must be carried off to insure a sound casting.

Machine Molding.—Molding machines are used with great advantage in green sand foundries wherever there is repetition work. Not only do they increase production, but they materially improve the quality of the castings, which, in turn, decreases the cost of the machining operations. They have the further advantage that they may be operated by comparatively unskilled labor. They may be classified under four general types, stripping-plate machines, squeezers, roll-over machines, and jarring or jolt ramming machines.

The stripping-plate type of machine is used for work which offers difficulties in drawing the pattern from the sand. The stripping plate itself is supported rigidly on the machine, the patterns being mounted on a drop plate working in guides. The stripping plate is cast to leave openings about one inch wide around the pattern. When the stripping plates and the patterns are properly set, this space is filled in with Babbitt metal, so as to form a close fit around the patterns at the parting line. In operation, the flask is placed on the machine, is rammed, vented, and struck off on the top; the pattern is then withdrawn downward through the stripping plate by a hand lever or an air-operated cylinder, and the mold is removed and set out on the floor. As pointed out in Chapter III, the impressions in gated patterns may be so arranged as to make one plate serve for both the cope and drag parts of the mold. Stripping-plate machines are well adapted to the manufacture of gears, pulleys, etc., having straight or nearly straight sides.

The squeezer type of machine may be operated by hand and merely packs the sand. In it the patterns may be carried on the two sides of a plate which is set between the cope and drag. Both boxes are filled with sifted sand and set on the machine. A lever or air cylinder is used to compress the sand against the plates. The cope is then lifted from the plate, the plate is lifted from the drag, and the two parts of the mold are set on the floor ready for pouring. This type of machine is used chiefly for thin work which vents easily and cools quickly, for the outer surfaces of the mold are apt to be rammed so hard that they would choke the venting of heavy castings. In another type of squeezer the cope and drag flasks are side by side, and the patterns, instead of being carried on two sides of the plate, are arranged on the same side, the cope impression being over the cope flask and the drag impression over the drag flask.

In the roll-over machine the pattern is carried on the top of a match plate; a flask is placed over it and the mold is rammed by hand or squeezed. The mold and pattern are then rolled over and the pattern is withdrawn upward, the operator rapping it meantime. The match plate with the pattern is then rolled back into its original position ready for making the next mold. (See Figure 7.) All three of the above types may be operated by hand or by power, and snap flasks are generally used. The production of a power squeezer will exceed that of a hand squeezer by 25 or 30 per cent. A power roll-over machine will handle a mold weighing 1000 pounds or more.

FIG. 7. HAND-OPERATED ROCK OVER MOLDING MACHINE
Henry E. Pridmore.

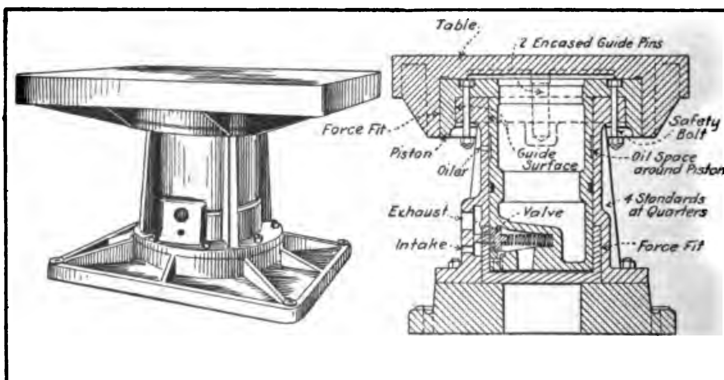


FIG. 8. MOLDING MACHINE AND SECTIONAL VIEW
American Molding Machine Co.

The jar or jolt-ramming machine, Figure 8, is used for all classes of work up to the largest floor work made in green sand; the only limit is the capacity of the machine itself, which varies from a few hundred to many thousand pounds. The patterns are mounted on heavy pattern or match plates; the flask is put in place, filled with sand, and clamped to the pattern plate. It is then lifted and placed on the jarring table which, in large machines, is on the level of the foundry floor, the working parts being below on a rigid concrete foundation. The table is "jolted" by an air cylinder which lifts it about four inches and drops it heavily on an anvil, packing the sand about the pattern. The number of blows required is determined by experience, but the time needed is only a small fraction of that consumed by hand ramming.

Various combinations of these types of machines are made, and many of their operations are automatic. Some are better adapted to certain classes of work than others, and intelligent selection of the type best suited to the work in hand should be made.

Carrier Foundries.—The full capacities of machine molding are best realized in carrier foundries (a specialized form of green sand foundry) where the mold, as soon as it is made, is placed upon a carrier which passes by the machine, instead of being set out on the floor. In the ordinary type of foundry the molds are arranged in rows on the floor, and toward the end of the day the pouring is done by the molders who bring the molten iron to the molds. In the carrier foundry the pouring is done continuously throughout the day

by men who do nothing else, the carrier bringing the molds from the machines to a portion of the floor near the cupola where the pouring is done. After the molds are poured, the castings cool as the carrier progresses; and after a few moments they are knocked out of the mold and run across a set of shaking bars which delivers the castings into a cooling crib, while the sand falls through the bars into the hopper of an elevator and is carried up overhead. New sand is then added, and is tempered and delivered by conveyors to chutes which open directly over the molding machines. The snap flasks used by the molder remain at the machines, and the molds are poured either without flasks or with only light steel bands around them to prevent shifting. This type of foundry is very efficient for long runs of small standard castings, such as pipe fittings, which cool quickly, but is not applicable for general work.

CHAPTER VI

FOUNDRY—MELTING, POURING, CLEANING

General Methods.—Three ways are employed for forming metals for industrial purposes:

First, by melting the metal and casting it in sand or other molds. This forms the basis of foundry work.

Second, by pressing the metal into the desired form. This may be performed while the metal is either hot or cold, either by blows under a hammer or by steady pressure. Forming the metal while hot is known as forging; forming it cold, as press-work or stamping.

Third, by cutting the metal with tools having single or multiple cutting edges. Grinding is simply a form of cutting. This method is usually used as a supplement to the others for machining castings or forgings accurately. The first two methods are most useful for giving the material its general form, but the work must usually be finished by the last method if it is to be close to size.

The Cupola.—Foundry metals are melted in the cupola, in the air furnace, in the open hearth furnace, in oil or gas furnaces, in crucibles, and in the electric furnace.

Of these, the cupola is the most widely used and is

the one generally employed for melting cast iron. It has the highest fuel economy and is the easiest to manipulate. The metal may be melted continuously throughout the day and be drawn off as desired. Figure 9 shows a section of a typical cupola. It consists essentially of a vertical iron shell, A, lined with fire brick, into which is charged alternate layers of pig iron and fuel. The shell and lining are carried on a plate, B, supported by four out-spreading legs at a height sufficient to allow the two bottom doors, C, to swing clear of the floor. The doors which form the bottom of the melting chamber are held up in place by a prop, D, while the cupola is in operation, and are protected during the heat by a bed of sand. When the run is over, and the cupola is to be cleaned, the prop is knocked out, the doors swing down, and the sand bed, with what remains of the charge, drops to the floor and is cleaned away.

Just above the bottom of the melting chamber is a large opening called the breast, filled with fire-clay, and through this is a smaller one, E, called the tap hole, which is used in drawing off the molten metal. This is closed by a plug of fire-clay while the charge is being held in the cupola. When it is drawn off, the plug is removed and a spout lined with a fire-sand mixture carries the stream of metal to the bull ladle. Above the level of the tap hole and on the opposite side is another hole, F, termed the slag hole, which is used to draw off the slag which floats at the top of the molten metal. Several inches above the slag hole are a series of large openings, G, called tuyeres, extending all around the melting chamber,

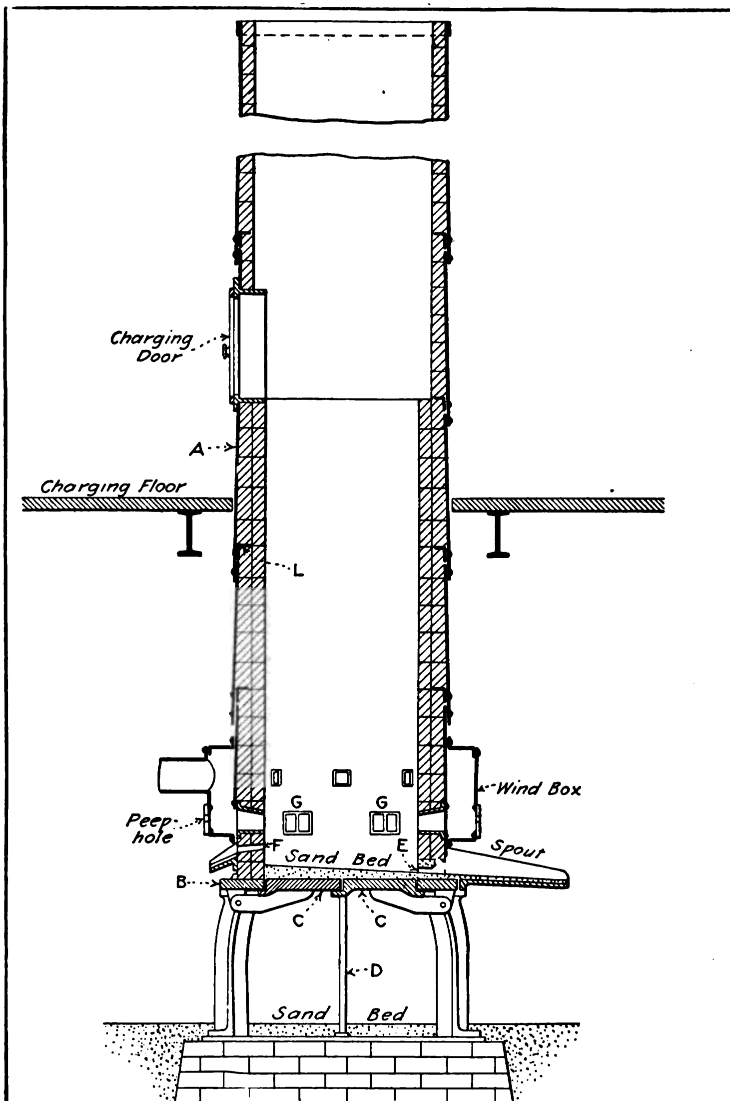


FIG. 9. SECTION OF A CUPOLA

which connect the melting chamber with the wind box which surrounds it. These openings, which are usually oblong, direct the air blast into the fuel bed. Peep-holes in the outer side of the wind box opposite the tuyeres enable the melter to look directly into the furnace. The height of the tuyeres above the bed varies with the class of work. Where the metal is being drawn off continually they may be as low as 8 or 10 inches above the sand bed. For large castings it is necessary to collect a large body of metal in the cupola and the tuyeres must be higher. For the largest work they may be five or six feet up.

The air blast through the tuyeres is furnished by fan or pressure blowers, and the quantity of air handled is very large, as it takes about 30,000 cubic feet of air to melt one ton of iron. The table, page 69, gives the average melting rate per hour for the various sizes. In large cupolas there are two sets of tuyeres, the upper row provides for the loss of wind should the lower row become partially clogged by slag. The fuel bed should extend above the top of these. The upper tuyeres have a smaller area than the lower as they are intended to give only extra air to burn the cupola gases and not to start a new melting zone. The combined cross-sectional area of the lower tuyeres runs from one-fifth of that of the cupola area for small cupolas down to one-tenth on large ones. The melting zone ranges from about one foot to four feet above the tuyeres. The fire-brick lining is supported at various heights by rings, L, riveted to the inside of the shell. This permits the separate renewal of the lining around the melting

zone, where the wear is most rapid, without disturbing the balance of the lining.

At a considerable height above the tuyeres is the charging door through which iron and fuel are charged in alternate layers. The width of the charging door for various sized cupolas is given in the accompanying table.

General Dimensions of Cupolas

Capacity in tons per hour	Inside diameter of lining Inches	Diameter of Shell Inches	Thickness of Lining		Charging Doors		
			Below Charging Door Inches	Above Charging Door Inches	No.	Height Inches	Width Inches
½ to 1	23	32	4½	2¼	1	16	16
1 to 2	27	36	4½	2¼	1	20	20
3 to 5	32	46	7	2¼	1	24	24
6 to 7	42	56	7	2¼	1	27	30
9 to 10	48	66	9	4½	2	27	30
12 to 14	60	78	9	4½	2	27	36
18 to 21	72	90	9	4½	2	27	36
24 to 27	84	102	9	4½	2	27	36

The efficiency of the cupola type of furnace is very high, as the melting ratio averages about one pound of fuel to ten of iron. This arises from the fact that the fuel and the iron are intimately in contact. This close contact has the disadvantage of exposing the iron to impurities, such as sulphur, which may be in the fuel, and therefore the cupola furnace cannot be used for many of the higher grades of cast-

ings. Yet on account of its cheapness of operation, its convenience, flexibility of control, and great capacity, it is used wherever possible.

The Air Furnace.—In the air furnace, shown in Figure 10, the metal is charged into the furnace through a charging door at the side; the fuel is burned in a separate chamber, A, and the gases are directed over a bridge wall and across the surface of the charge, B, which lies on the sand bed, C, and are carried off by the chimney at the left. As the gases in their passage cling to the top of the furnace, the metal is heated more by radiation from the incandescent top and side walls than by direct contact. Since there is no direct contact between the metal and the fuel, fuel impurities in the latter are less troublesome than in the cupola, and a better qual-

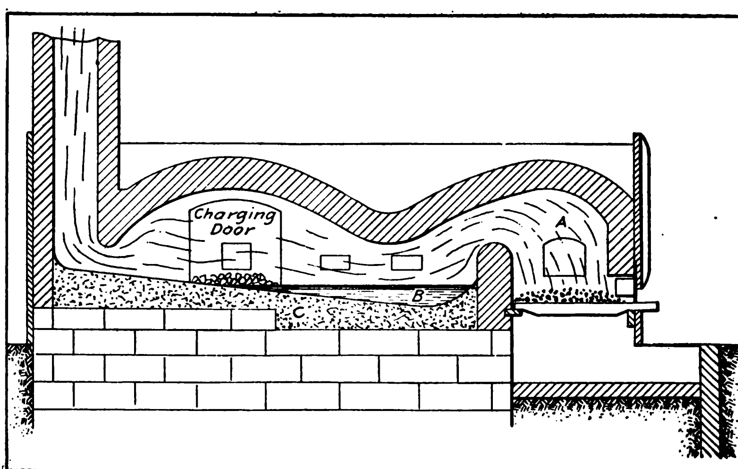


FIG. 10. SECTION OF AN AIR FURNACE

ity of metal is obtained. But the qualities which give the air furnace a purer output decrease its melting efficiency, and the melting ratio, which in the cupola will run from one of fuel to eight or ten of metal, in the air furnace will not do more than one to four. It will, however, give a large amount of high-grade metal at one tap, and heavy pieces of scrap may be used which are difficult to handle in the cupola.

Open-Hearth Furnace.—The open-hearth furnace is used principally for melting steel, and, to some extent, malleable iron. It is somewhat similar to the air furnace except that it has two gas chambers, A and A′, and two chambers, C′ C (Figure 11), so arranged that the direction of the flame can be reversed. The checkered brick-work in C′ and C is used for preheating the air so that it enters the furnace at nearly 1000 degrees Fahrenheit. This furnace gives a high-grade product and has a heating ratio of about one to six. By-product or producer gas is generally used as fuel. The gas from the chamber, A, and heated air from C′ unite as they enter the furnace, pass over the top of the charge, B, and then out through checkered brickwork, C, which absorbs a large part of the remaining heat. When the gases are reversed, the checkerwork, C, takes up the pre-heating and the waste gases heat the brickwork, C′, on the other side which was cooled down during the previous run. The direction of the gases is reversed about three times an hour.

Oil or Gas Furnaces.—Figure 12 shows an oil furnace of the type used in a brass foundry. These are mounted on trunnions to permit tilting and pouring,

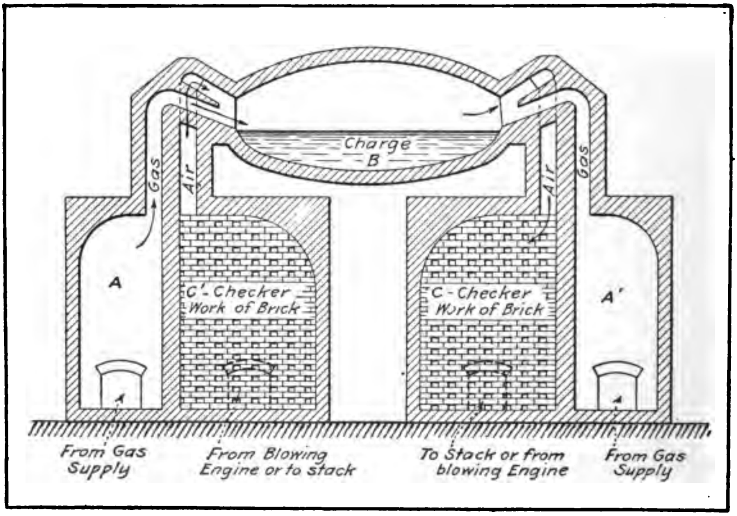


FIG. 11. DIAGRAMMATIC VIEW OF OPEN-HEARTH FURNACE WITH REGENERATORS

and the fuel is supplied through one of the trunnions at one end. The flame plays across the charge and out at the top. The metal to be charged is first laid on top of the furnace while the fire is on, where it is gradually warmed and finally is pushed into the chamber as required. When oil is used for the fuel, it may be fuel oil, crude oil, distillate, or kerosene. Gas may be used in the form of natural gas, water gas, or city gas. Producer gas is not suitable, since it is too low in calorific value to maintain the temperatures required. The capacity of these furnaces varies from 500 to 1250 pounds at a charge, and about 1½ to 3 gallons of oil are required to melt 100 pounds of steel.

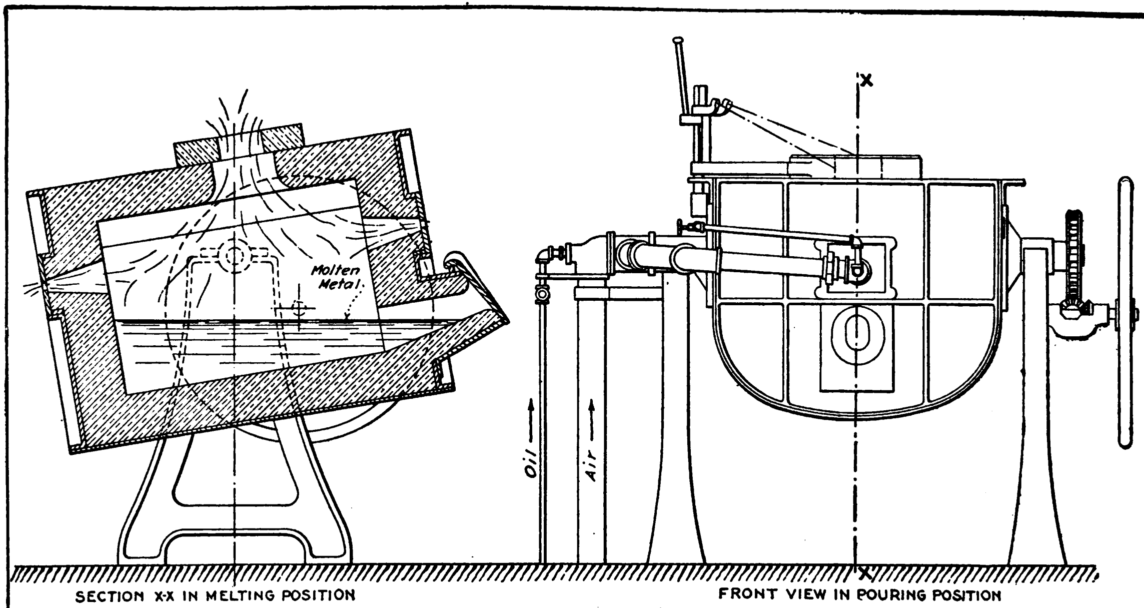


FIG. 12. OIL FURNACE OF THE REVERBATORY TILTING TYPE

Crucible Furnace.—The crucible furnace is shown in Figure 13. It is used chiefly for melting small special mixtures in brass foundries. The metal does not come into direct contact with the fuel but is placed in refractory crucibles which are covered and set in the furnace. Graphite is the principal ingredient used in the construction of the crucibles, bonded with fire clay, as they must be strong and tough even at a high temperature. They should be brought slowly to a red heat before using, and the charge should be carefully packed, in order to allow expansion of the metals inside before they melt, otherwise the crucible may break. The fuel may be hard coal

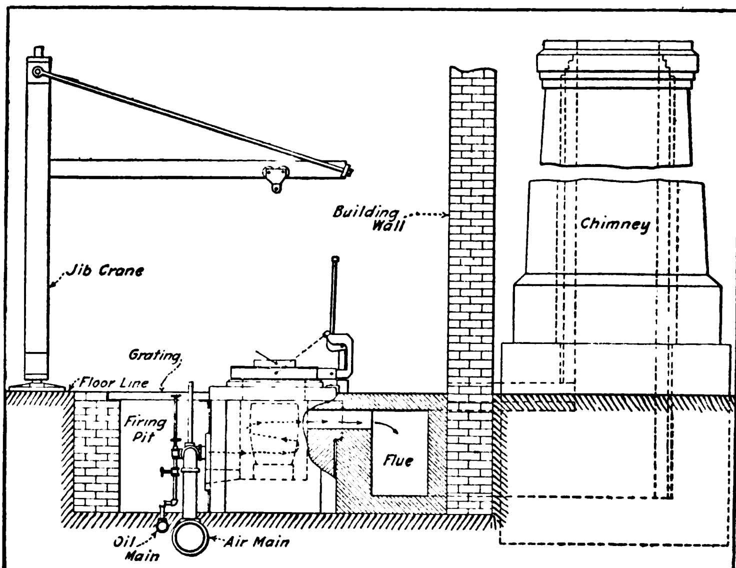


FIG. 13. CRUCIBLE FURNACE FOR MELTING BRASS

or coke, sometimes gas or oil. When the charge is melted, the crucibles are lifted out by means of tongs and emptied into serving ladles. Closed crucibles are used in brass foundries because alloy metals, especially zinc and tin, burn if exposed to the air while melting. If the casting is so large that one crucible will not suffice, several furnaces must be used and their crucibles discharged into one large ladle.

Electric Furnace.—Electric furnaces are very expensive in operation and little used except for making high-grade steel in small quantities. Their advantage lies in the accurate control of the chemical constituents during melting.

Ladles.—The molten metal is transported from the furnace to the mold in ladles. These range in capacity from 25 or 30 pounds up to 60 tons. The large ladle that is located permanently at a cupola into which the spout discharges is called the bull ladle. It is mounted on trunnions and is tilted to pour metal into serving ladles which are brought to it. Serving ladles may be carried by crane, overhead trolley, or by hand. Hand ladles may be single or double, depending upon whether they are carried by one or two men. All ladles are made of metal, with a refractory lining to protect them from burning. The smaller ladles are provided with a lip or spout from which the metal is poured. Large ladles are carried by cranes and are controlled by gears to facilitate pouring and to prevent accidents from too rapid turning. Very large ladles, such as those used in steel foundries, are not turned in pouring but are provided with a tap hole in the bottom. The lining

in small and medium sized ladles will vary from three-fourths inch to two inches in thickness according to size. Large ones are lined, first, with fire brick and then daubed with a clay mixture similar to a cupola lining. Ladles must be well dried before using.

Pouring.—In pouring the molds care must first be taken to skim off the slag. With large ladles, this should be done before leaving the cupola and again as the metal is poured. A skimmer, which is a long iron rod, is used for this purpose; the end of it rests across the top of the ladle near the pouring spout to hold back the slag while the metal runs free.

Great skill is required in pouring molds, as the speed with which the metal should be poured varies with the character of the work. It should be done slow enough to allow the gases to escape and yet fast enough to keep the metal from chilling in the mold and forming "cold-shuts," as they are called. Care must be exercised to keep the stream steady and not to "spill" into the mold; the basin at the gate of the mold should be just kept full. It is of vital importance that the pourer gauge correctly the amount of metal required, for if he has not enough metal in his ladle to fill the mold and must use the second one, he is practically certain to lose his casting. Any metal remaining after pouring should not be allowed to chill or freeze in the ladle, but should be poured into a larger ladle or emptied on the floor. Pig beds are usually provided near the cupola for this purpose.

Defects of Castings.—The accompanying table shows the principal defects of castings, with their causes and cures:

Poured Short:

Cause—Amount of metal in the ladle misjudged and the mold not filled.

Cure—Have enough metal.

Blow Holes:

Cause—Gases pocketed in the mold, sand packed too tight, sand too wet, or poor venting.

Cure—Provide adequate venting.

Cold Shut:

Cause—Two streams of metal meeting in the mold which are too cold to fuse together.

Cure—Use hotter metal or have a thicker section.

Sand Holes:

Cause—Loose sand washing into the cavity and fusing into the metal. Too little facing.

Cure—Have a stronger mold, use more facing. If necessary, use dry sand mold.

Lifts:

Cause—Cope floated off drag by the metal.

Cure—Weighting or clamping the cope.

Shifts:

Cause—The cope being misplaced sidewise with respect to the drag so that the two halves of the impression will not register.

Cure—Proper registering between cope and drag.

Core Shifts:

Cause—Cores breaking or becoming misplaced.

Cure—Stronger cores and more careful setting.

Scabs (Small, wartlike projections on the surface of the casting):

Cause—Mold washing off and being carried away.

Cure—Stronger mold, better rammed, and more facing.

Swells (Bulges in the casting):

Cause—Too soft ramming.

Cure—Proper ramming.

Shrinkage (cracks):

Cause—Unequal cooling or mold too firm to give as the metal cools.

Cure—Re-design of the part or lighter packing in the mold.

Warping:

Cause—Pattern may have warped; casting may have lugs on one side retarding the shrinkage, or sand may be packed harder on one side than on the other.

Cure—Correcting the pattern or relief of the strain.

Cleaning.—After the castings are poured sufficient time should be allowed for the metal to set. In small castings this may be a matter of a few moments; in very large ones, it may take a week or even more. If castings are knocked out too soon, shrinkage strains and cracks result. When the castings are removed from the sand, the gates are broken off and turned into the scrap pile for remelting and the castings are collected and carried to the cleaning room as molding floor space is too valuable to be tied up with work which can be done elsewhere. The cores and core irons are dug out and the fins (thin sheets of metal which seep out between the cope and drag) are chipped off. In large work much of the cleaning is done by hand, but it is greatly facilitated by the use of air chipping-hammers, and for very large work, especially large steel castings, the oxy-acetylene flame or the electric torch is used to cut off risers, etc.

Tumbling.—Tumbling is the most effective way of cleaning small castings which are fairly uniform in size and, in general, not over 50 to 100 pounds in weight. Tumbling barrels are made of steel plate and lined with chilled-iron bars to protect the shell.

The bearings of these barrels are sometimes hollow and connected with an exhaust system to draw off the dust. As the barrels revolve, the castings tumble over and over, cleaning each other in twenty minutes or half an hour. To facilitate the cleaning, shot iron and hardened stars are thrown in and revolved with the castings. When removed from the barrel iron castings will show a clean, smooth, grey-colored surface. From the tumbling barrels the castings may be taken to the dry emery wheels for grinding off the remnants of the flash and the sprue stubs.

Pickling.—Where much machining is to be done, the presence of sand and scale on the surface of the casting plays havoc with the cutting tools. Such particles may be removed by the process of pickling. This consists in washing the castings in dilute sulphuric or hydrofluoric acid diluted with water in a ratio of 1 to 8 or 1 to 10. They are left in this bath long enough to cut out the sand and the hard skin of iron oxide, which is formed when the iron strikes the damp mold, without seriously affecting the casting. After removal from the pickling bath, the castings are rinsed in water which should be hot enough to heat them so that they will dry rapidly.

Sand Blast.—Small and delicate castings which cannot be tumbled with safety may be cleaned by the sand blast. Sharp, clean sand is blown against the surface by compressed air at about 10 pounds pressure, giving the casting a beautiful finish. The work requires a considerable apparatus and involves a separate room. The operators must be protected by helmets and supplied with fresh air through a hose.

CHAPTER VII

FORGING METHODS

Hand Work.—Many metals may be formed or shaped either hot or cold, but the term forging is confined to the working of heated metal under blows or heavy pressure. The forming of cold metal by press work, or cold stamping, requires more power, because of the higher resistance of the metal to a change of shape; but it is more accurate than hot work, as the uncertainties of shrinkage are eliminated, and is faster than forging because the work may be manipulated by hand instead of by tongs. Pressing and stamping machines form an entirely different class from those used with hot work and are located in a different department. Hence, hot work, or forging, only will be taken up in this chapter.

In the past fifty years the work of the forge shop has been undergoing gradual changes. Hand methods have been supplemented by forging machinery, and the field has extended in two directions: Steam hammers and hydraulic presses have permitted an enormous increase in the size of forgings, while drop hammers and the various other forms of power hammers have introduced manufacturing methods in a refined form. On the other hand, the foundry has been cutting into the field of the forge shop through

the increasing production of steel and malleable iron castings now used for many articles which formerly were forgings.

The principal materials which are forged commercially are machinery steel, tool steel, wrought iron, bronze, copper, and aluminum. Rough stock is usually in the form of merchant bars for small and medium sized work and of billets for large forgings.

The various methods of forging may be grouped as follows:

Hand work
Welding
Steam hammer work
Drop forging and power hammer work
Heading and upsetting
Hydraulic press work
Rolling
Drawing
Extrusion work
Pipe bending.

Hand forging will always have its place for all small and special work, for making the special cutting tools used in every machine shop, and for the hand tools, special rivets, bolts, etc., on large engineering operations. But little tool equipment is required which can be easily moved from place to place.

The Forge.—The equipment for hand forging involves a forge fire. This may be either a permanent fixture in the case of blacksmith shops in manufacturing plants, or portable so that it may be set up anywhere—on a platform, on an engineering structure

under erection, or in a shanty by a railroad tr The usual fuel for small fires is soft coal, but oc sionally charcoal, coke, or hard coal is used. I should break easily and burn freely with little clinker. The necessary air is furnished from beneath through tuyeres. In permanent forges the tuyeres are connected with a general blower system serving the forge shop. For portable forges the bellows used from time immemorial are giving place to small, hand-operated, rotary blowers. The fires should be kept as small as possible, but should be deep enough to make sure that the air blast is distributed evenly through the coal and does not strike open spots. This is necessary for even heating, for the hottest part of the fire follows the blast. A blacksmith will often stir the bar he is heating to loosen it from the coals and to allow the air freer access to the coal immediately around it. Fuel is usually added to the fire at the side and is gradually worked in toward the center of heating. Fires may be either oxidizing or reducing, according as there is or is not an excess supply of oxygen through the air blast. An oxidizing fire should be avoided, as it produces scale or iron oxide which wastes the metal and interferes with forging. When the right amount of air is admitted the iron will come out bright and clean.

For permanent forges, such as are used for tool dressing in machine shops, gas or oil are the best fuels as they are cleaner and afford easy and accurate control of the heat. They are generally used on drop forging and large work for similar reasons. Care

must be used to heat large forges slowly and uniformly and to avoid oxidation. If the surface is too hot and the interior too cold, transverse cracks will appear on the surface of the work being forged. If the conditions are reversed and the inside is hotter than the outside, longitudinal cracks will appear. Steel should be forged with as few heats as possible and should not be worked or finished when too cold. There is more danger of injuring the stock by working it when too cold than when it is overheated. Steel should not be allowed to remain in the forge fire longer than is necessary, or the material will recarbonize. For very large work a reverberatory or air furnace is used which is somewhat similar to the air furnace shown in Figure 10. These are not economical of fuel, but they provide means for the uniform heating of large work. The billets, or material to be heated, are inserted through a door at the end, and the heating is done by the radiation from the roof and sides of the heating chamber. The fuel most used for these furnaces is soft bituminous coal, and the furnaces are used in connection with steam or power hammers where the work is large and heavy.

All hot forgings are subject to shrinkage, as in the case of castings, and for accurate work it is necessary to allow for this. The shrinkage amounts to about one-eighth inch to the foot.

Tools.—The important tools in hand work are the hammers, anvil, and tongs. The ordinary single-hand hammer has a handle about 15 inches long and a head weighing about 1½ pounds. Figure 14 shows some

of the more common forms of heads. The eye of the head is usually set so that the greater weight is on the face side, as heavier and more accurate blows may be struck than if the weight were evenly balanced. Sledges, which are heavy hammers used by a helper and swung with both hands, vary in weight from 5 to 20 pounds; they average about 12 or 15 pounds.

The first requirement of a blacksmith's anvil is weight. It should be able to absorb its own shocks, and any anvil which has to be braced is practically useless. The next requirement is that it have a hard face, for it must be able to withstand the roughest kind of use. Modern anvils usually have a wrought iron body to which is welded a hardened steel face. The well-known shape of an anvil is a gradual development through many generations. At one end is a tapering horn, at the other a wedge-shaped projection having a square hole into which auxiliary tools may be set. It is mounted on a heavy wooden block, about 20 inches high, to give it a firm but elastic foundation, and its weight usually runs from 150 to 300 pounds.

The tongs, some varieties of which are shown in Figure 14, are made of steel and vary in size and shape to meet the needs of the various articles handled. The handles are long and often are provided with a slip ring which can be slid along to clamp the tongs upon the work.

Some other auxiliary tools are set hammers for working into corners and narrow places, flatters for smoothing out high surfaces, swages for finishing

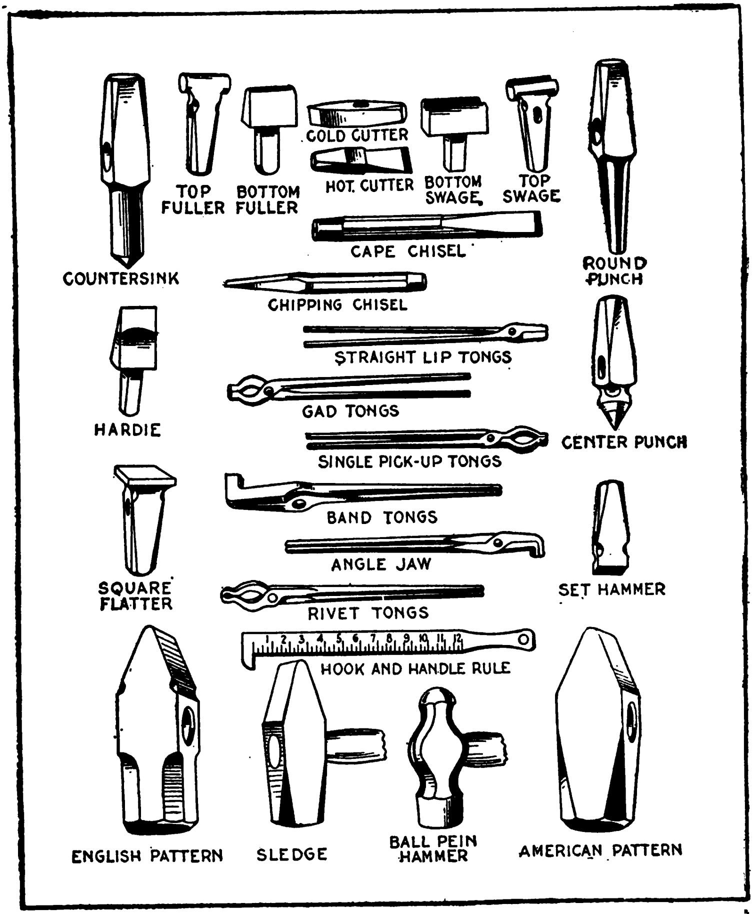


FIG. 14. HAND FORGING TOOLS

round and convex surfaces, fullers for working grooves or hollows into shape, swage blocks which contain holes of various sizes and shapes, steel calipers for measuring the work, and the necessary fire tools.

Operations.—The operations of hand forging cover almost every type of forging work. The principal ones are drawing, upsetting, riveting, bending, shrinking, and welding.

Drawing consists of hammering the piece on the side and rotating it at the same time between each blow. Under the influence of the hammering the metal spreads in all directions, but the metal forced sidewise by one blow is driven back by the next, while the displacement of the metal endwise is unobstructed. The effect is to work the metal longitudinally, and a short piece of large diameter may be drawn out into a long one of small section.

Upsetting is the reverse of drawing; a long, thin piece is forged from the end and spread out sidewise to form a head (as in the case of bolts), or sometimes a bulge in the middle.

Riveting is a special form of upsetting where heads are formed in place on rivets to secure two pieces of metal together.

Bending, which needs no explanation, is usually done over the edge of the anvil or around the horn.

Shrinking is the setting of forged rings tightly on a solid core or bar. The ring is forged hot to a sliding fit, slipped over the core, and allowed to cool. The shrinkage causes the ring to grip the core with tremendous force.

Welding.—Welding is the process of joining two pieces of heated iron or steel by placing them together and hammering the joint. It is one of the most skilful branches of the blacksmith's art. The heating must be done evenly and cleanly in a reducing fire; too high a temperature is sure to form scale, and at too low a heat the metal will not weld. The proper range of temperature, constituting what the blacksmith calls "welding heat," is therefore narrow.

The presence of scale or iron oxide is the great evil of welding. It may be formed in the fire and will collect on the heated metal from contact with the air. The process of welding is a mechanical one, and there is no direct chemical action. It is facilitated by the use of a flux, usually sand or borax on the surface to be welded, which unites with the scale and forms a slag that melts at less than welding heat and is forced out in the hammering. In "scarfing," or preparing the pieces for welding, the surfaces to be joined should be convex so that they will touch first in the center. This facilitates forcing out the slag. If the surfaces are concave, some of the slag is likely to be pocketed in the joint and cause an imperfect weld.

Dissimilar metals, such as steel and wrought iron, or tool and machinery steels, may be welded together, but they require skilful handling as the welding heats of the two metals are not the same. Imperfect welds may arise from poor contact, insufficient hammering, and flux left in the joint; from insufficient fluxing, so that the scale is not all cared for; from too high or too low heat, and from impurities in the metal. Where the carbon in steel runs over 1.1 per cent it is

difficult to make a weld; and cast iron which contains 2 per cent or 3 per cent of carbon cannot be welded at all by the ordinary methods. Silicon, phosphorus, sulphur, and manganese all lower the welding qualities of iron. The purest and softest steels weld the best. For these reasons the efficiency of a weld is uncertain; it will average from 70 per cent to 80 per cent but may be as low as 50 per cent. Welds made with a steam hammer are stronger than hand welds of the same size. The art of welding has received enormous development in recent years and methods other than the use of a forge fire and hammering will be discussed later.

Steam Hammer Work.—Steam hammer work is a development from hand forging and differs from it only in the size of the work handled. Three types of steam hammers are used: one where the hammer is lifted by steam and drops of its own weight; one where exhaust steam is admitted above the piston and by its expansion increases the force of the blow, and a third where live steam is used above the piston throughout the downward stroke.

The first class is used for very large work and the weight of the hammer ranges from 25 to 125 tons. Its disadvantage lies in the fact that the height of the piston in the cylinder from the lower cylinder head varies with the thickness of the work and forms a clearance space which must be filled with live steam. In the second class the consumption of steam is less, the force of blow is greater and a larger number of blows are given in a minute, but the reliability of operation is more or less uncertain. The third

class is the most widely used: here the weight of hammer varies from one to 25 tons; the number and force of blows can be regulated by throttling the steam, and the control is such that the weight of the hammer only may be used for light blows, while steam is employed for the heavier blows. These hammers work rapidly and are provided with automatic reversing gears, so that as many as 350 blows a minute may be obtained.

The frames of steam hammers may be single or double (Figures 15 and 16). The double frames used on the larger sizes are stronger than the single frame, but freedom of access about the anvil is restricted. In both types the hammer head usually is guided by means of slides on each side. Open frame hammers, as they are called, are used for certain classes of work where slides would be troublesome. In them a large piston rod and small head in one piece are operated without guides and afford free access to the anvil on all sides.

The anvil of a steam hammer is a large casting faced with steel and carried on a separate foundation from the rest of the hammer to lessen the shock on the working parts. In good practice the weight of the anvil should be not less than ten or twelve times that of the hammer head; the heavier the better, for the efficiency of the hammer is increased as the weight of the anvil is increased.

A rough rule for determining the size of hammer required is to multiply the cross section, in square inches, of the work to be forged by 80 for steel and by 60 for wrought iron. For example, a steel forging

FIG. 15. SINGLE-FRAME STEAM HAMMER
Niles-Bement-Pond Co.

FIG. 16. LARGE DOUBLE-FRAME STEAM HAMMER
Niles-Bement-Pond Co.

5 by 5 inches would call for a 2000-pound hammer. The question is often asked, "What is the force of the blow?" It is impossible to tell, if by this is meant the pressure produced. The energy, represented by the weight and velocity of the moving parts as they strike the work, is determinable; but the pressure which is exerted varies inversely with the distance in which they are brought to rest after they strike the work. Thus, while the forging is hot and soft, the hammer sinks into the metal some distance and the pressure is comparatively low; and as the forging cools, the metal grows harder and the pressure increases rapidly. There is, therefore, no feasible way of rating hammers other than by the weight of their falling parts.

The field of the steam hammer is that of general forging on large and special pieces. Sometimes dies are used, but if so, they are only of the simplest character. Steam hammer work has been cut into in recent years from two directions. The hydraulic press is preferable for very large work, as it produces sounder forgings and has the further advantage of quietness of action; while the heavy blows of a large steam hammer may often cause so much vibration and noise as to be objectionable to an entire neighborhood. The other restriction of field comes from the increasing use of steel castings which do away with the necessity of uncertain welds in built-up work, such as the side frames of locomotives.

Power Hammers.—Drop hammers are confined to small and medium sized work and are used where many pieces of the same kind are needed. Drop

forging is becoming an art in itself and is so important that it will be taken up separately.

Power hammers other than drop hammers are used in a wide variety of types. The oldest, the helve hammer, now largely obsolete, consists of an oscillating wooden beam pivoted at one end and carrying at the free end the upper half of a pair of dies, the lower half being carried in an anvil below. The beam is lifted by a rotating shaft carrying a series of cams, each of which raises the hammer and allows it to drop suddenly. This type has been used from mediaeval times. The modern development of the helve hammer is seen in the Bradley hammer, Figure 17. In this the beam is operated by a swinging frame driven from a rotating shaft. Between the frame and the beam rubber cushions are interposed, the effect of which is to soften the action on the driving mechanism and to give a quick blow.

The Beaudry hammer, Figure 18, which is a crank-operated power hammer, is also widely used. The head of this hammer has an internal curve or track. Two steel arms, acting as springs, carry hardened rollers which bear on the curved surface and transmit the power from the rotating shaft to the hammer head. The action gives a quick stroke and allows a rebound the instant the blow is made.

Another type of power hammer is the pneumatic hammer operated by compressed air supplied by an air compressor integral with the frame. The purpose in all of these types of hammers is to give a quick, sharp blow. They are started and stopped by a foot treadle: by varying the pressure on the treadle

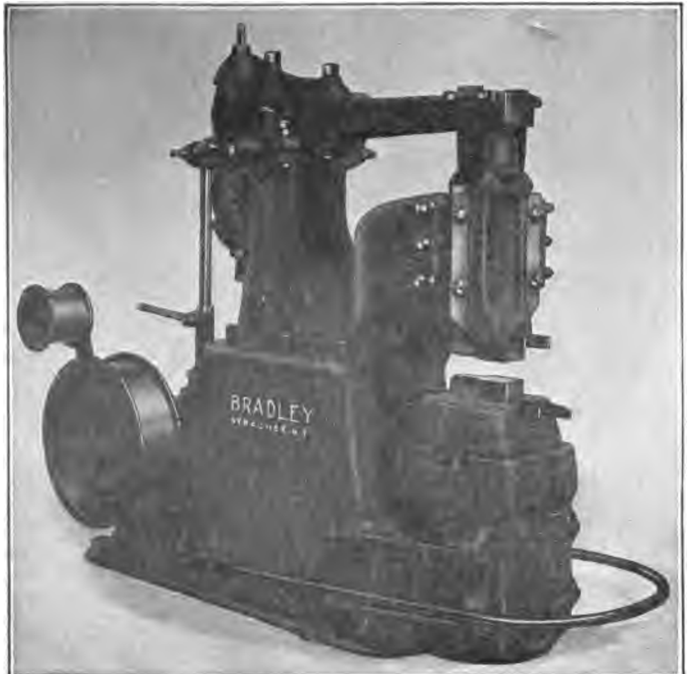


FIG. 17. BRADLEY UPRIGHT HELVE HAMMER

FIG. 18. BEAUDRY POWER HAMMER

any desired speed or force of blow within the capacity of the machine may be obtained. They are used with and without dies for drawing out handles and for surfacing round work. Hammering is continued until the work is cold. The work is rotated meantime and a heavy stream of water is played upon it, which cracks off the scale and turns out a smooth forging very close to size and requiring little or no machining.

Headers and Upsetters.—For upsetting heads on the ends of long thin stock, heading and upsetting machines are used. The dies for the purpose are usually in three parts, one on the movable head of the machine (see A, Figure 19), and the other two, B and B′, carried by the main frame. These two dies, B, B′, in the main frame separate to allow the introduction of the heated bar. They are then closed together, and the third portion of the die, A, on the movable head, advances and drives the hot metal into the impression in the other two. This type of machine is used for forging bolt heads, automobile valves, and so forth.

Hydraulic Press.—The hydraulic press, Figure 20, consists essentially of a heavy frame, an anvil, and a moving head which may or may not be provided with dies. The head is operated by a hydraulic cylinder which creates the pressure used in the forging. The supply of water for the cylinder is controlled by a valve and is furnished by a high-pressure water pump. This type of machine works, not by blows, but by dead pressure. It is used for all sizes, but more especially for large work. The effect of a hammer blow is greater along the surface immediately

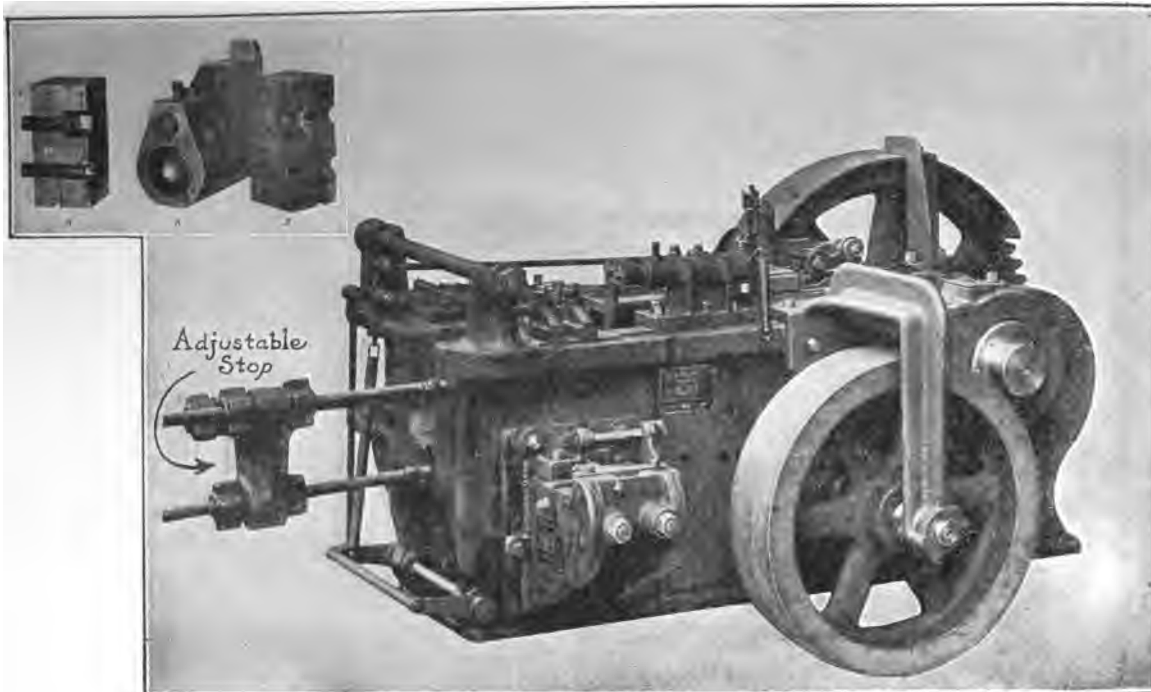


FIG. 19. BOLT HEADING, UPSETTING AND FORGING MACHINE
Ajax Manufacturing Co.

FIG. 20. 1100-TON HYDRAULIC FORGING PRESS

Southwark Fdy. and Machy. Co.

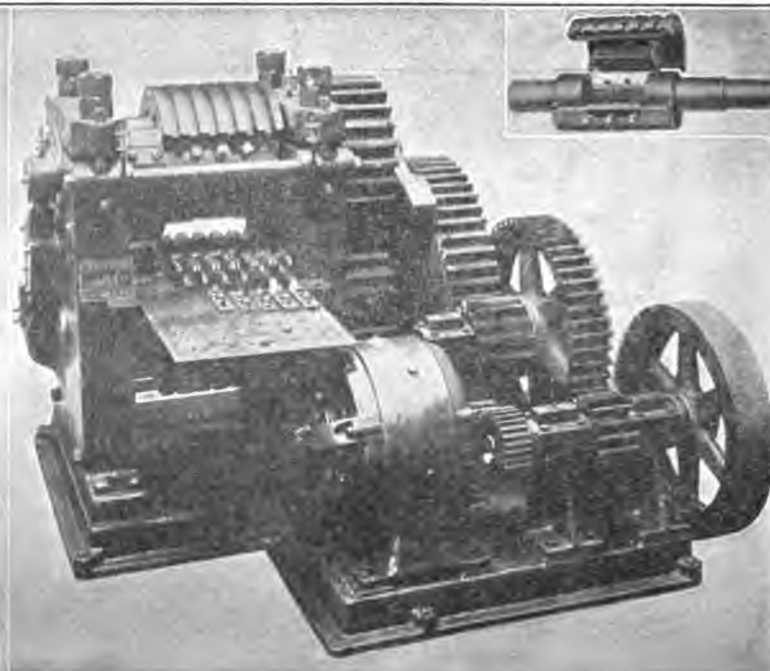


FIG. 21. FORGING ROLLS

Ajax Manufacturing Co.

Insert in upper corner shows the impression half of the rolls above, and the free half below.

under the hammer, and the metal tends to work sidewise; while the slow, remorseless action of the hydraulic press allows the pressure to reach every part of the forging and, therefore, it produces sounder work. It has an advantage in connection with die forging from the fact that cast iron dies may be used. Although they may also be used in drop hammers, their use is not general and their life is very uncertain, as the metal crystallizes and eventually gives way. Consequently, steel dies are ordinarily used; these are expensive to make, but where many pieces are to be made, the charge for dies may be distributed over them and is not serious. Where there are but a few pieces, the ability to cast the impression lowers the die cost and thus permits the use of die forging for smaller quantities than would be justified with steel dies having cut impressions. As already pointed out, the action of the hydraulic press is very quiet and it is now used almost entirely for very large work, such as armor plate forgings, heavy shafts, and so forth. The plant required—which includes not only the press itself, but the necessary high-pressure pumps and connections—is very expensive, and this forms a serious limitation to its use. The hydraulic press, however, is finding increasing favor, and plants have been installed of enormous size—one used in the Bethlehem Steel Company has a capacity of 14,000 tons.

Rolling.—As the name implies, this process consists of rolling the metal out between the curved surfaces of rollers. It is used for long and thin, or narrow, work usually of uniform cross section, such as flat

plates, steel rails, I-beams, channels, and angles, as well as for merchant shapes, which are bars in standard sizes of round, square, and rectangular section. The rolling process forms the backbone of the steel mill industry and is also important in the brass industry. Rolling mills, vary in size from small ones which are operated by hand or gear-driven from shafting, to the largest sizes which, with their auxiliary equipment, driving engines, etc., fill the whole of a large building and represent an enormous investment.

Rolls producing bars and shapes fall under two classes, which are known as the two-high and three-high rolls. In the two-high roll it is necessary to reverse the direction of the roll for the return pass or to send the material back for the next rolling. The material is usually put through the roll a number of times; each pass through a smaller groove in the rolls reduces the section of the bar and increases its length. The distance between the centers of the rollers is adjustable, so that the size of the section to be rolled may be varied. The three-high roll is similar to the two-high, except for the addition of a third roll. All three rolls revolve continuously, so that adjacent surfaces of the first and second rolls are moving in one direction while those of the second and third are moving in the reverse direction. The material, therefore, which has been passed between the lower and middle rolls may be returned between the middle and upper roll with a consequent saving of time in handling.

The rolling process is used not only for continuous

work of uniform section, but also for forging separate pieces which are relatively long and narrow and vary in cross section, such as axles, sword blades, knife blades, wrench handles, etc. Figure 21 shows a forging roll of this type. The dies, with the impressions cut in their surfaces, do not extend entirely around the rolls; hence, when the free sections of the upper and lower dies are opposite each other, there is an opening between the rolls into which the stock is inserted, as shown in the figure. The rolling motion is toward the operator, so that when he reaches forward and inserts material between the rolls, it is caught by the dies and is rolled back toward him. In this manner there is no danger of the operator catching his hands in the machine. As in other rolls, there may be a series of impressions, each approaching the desired finished shape. This method of forging is rapid and requires less power and a lighter machine than would be needed to forge an article broadside.

Drawing.—The drawing process is used for the manufacture of wire. The metal is first rolled into bars, until the section is small enough to be handled by the drawing press. One end of the bar is reduced in section and is then thrust through an opening of the desired size and shape in a hardened die. The end is seized and the rod drawn through the opening, reducing its cross section to the size of the hole. Successive passes are made through successive dies, each of which reduces the section a certain amount. Metals may be drawn either hot or cold; if the latter, they will harden and become brittle after a certain percentage of reduction. Ductility may be restored

by annealing, that is, by heating and subsequent cooling, and the process may then be repeated with alternate drawing and annealing down to the manufacture of the finest wire.

Extrusion Process.—This is the reverse of drawing and might be compared to a potato ricer on a large scale. The metal is passed through dies of the required size and shape, but it is forced or extruded through instead of being pulled through as in the drawing process. This method is used in the manufacture of brass bars and shapes. It requires enormous power which is usually supplied by a large hydraulic press. An ingot is placed in an enclosed space and a ram coming forward drives the hot metal through the holes in the die at the other end. By this process an ingot six or eight inches in diameter and several feet long may be reduced to a number of bars one-half inch or so in diameter, which may be taken to draw benches and finished by the more accurate process of drawing. The extrusion process can be used for the production of fairly intricate shapes, such as stair railings, which cannot be made by the drawing process.

Pipe Bending.—Another form of forging which may be done either hot and cold is known as the pipe bending process. Any one who has bent a paper roll knows that a tube will collapse at the point of bending unless the sides are prevented from coming together. A metal pipe which is to be bent is filled with sand or other resistent material which will stand heat. Then, since the pipe cannot collapse, the fibres on the outside of the bend are stretched, those on the

inside are compressed, and a clean bend is made without change in the shape section. Care must be used in bending welded pipe not to open up the joint of the weld. For this reason such pipes are usually bent with the weld on the side where the length of the pipe is neither increased nor decreased and where the tendency to open up the weld is least. Forms are used to give the desired radius of curvature; for small pipes, a traveling roller bends the pipe around a core; for large piping, such as steam mains, etc., radius blocks are set in a steel floor-plate and the ends of the pipe are pulled around by windlass and tackle.

CHAPTER VIII

DROP FORGING

Utility.—Drop forging is an application of manufacturing methods to the forging process, developed by the American gun manufacturers about the middle of the last century. It consists of hammering the material between two dies, one of which is carried on the anvil and one on the face of the hammer, and forcing the material into accurately registered impressions cut in the faces of the dies. Drop forgings are produced in an almost infinite variety of shapes and can be made close to size and in great quantities.

Great advancement has been made in the art and its scope and usefulness are being steadily widened. It is now an important element in the manufacture of many types of interchangeable products, such as fire arms, sewing machines, automobiles, machine tools, and so on. The field of the drop forging process is confined chiefly to smaller forgings, not so much from any mechanical limitation of the process itself as from the fact that few large forgings are produced in quantities sufficient to warrant the expense of the necessary dies. Automobile steering parts, crank shafts and axles represent about the limit of drop forging at the present time, but there is no reason why the process may not be extended to larger work if occasion requires.

Two auxiliary processes accompany or follow the work of forging. During the forging a small amount of material, called "flash," is forced out of the impression into a thin space provided between the face of the dies. This is trimmed off either during or after the forging process. During the forging, also, a thin scale of iron oxide is formed which is removed later by pickling or in the sand blast.

The drop forging process is subject to some limitations. Forging dies correspond roughly to the cope and drag of the sand mold used in the foundry, and impressions in the dies to the impressions left in the molds when the pattern has been removed. In foundry work the sand mold is temporary and is destroyed after the casting has been poured, therefore, the casting may have any shape. In drop forging the dies are practically permanent; consequently the forging must have no enlargements or bosses which would prevent its being lifted freely out of the impressions in the die. Furthermore no cores are possible, as in the case of foundry work, on account of the heavy hammering, of the obstruction they would offer to the distribution of the metal, and of the inability to get them out of the finished forging.

Drop Hammer.—The drop hammer consists essentially of a heavy steel ram sliding between two vertical guides mounted on an anvil or block which forms a base. The upper die is keyed to the hammer head and the lower die, in accurate register with the upper, is keyed to the base. In the early form of drop hammers, used in the Colt Armory about 1860, the heads were lifted by a vertical rotating screw to a

definite height which was determined by an adjustable trip. This method was slow and has long since been superseded. For light work, such as jewellers' hammers, the head is lifted by a strap which runs up over a pulley and down to the floor where it is operated by foot power. For slightly larger hammers the belt may be operated from above by a pulley with various forms of release mechanism to allow the hammer to fall. While a few belt and rope drops remain, the board drop has, in the East, practically superseded all others for medium-sized work and the steam drop for large work. In the Middle West, the steam drop is used for light and medium work also.

In the board drop, Figure 22, one or more boards are keyed into the top of the hammer head, and two rollers at the top of the hammer are pressed together and roll the board upward. When the head has reached the height desired, a trip on the side of the hammer head operates a latch rod which, in turn, spreads the rollers apart and allows the hammer and board to fall freely on to the work below. As the hammer reaches the bottom of its stroke the latch rod throws the rolls together again, and they roll the board up to the top of the stroke. The operation is controlled by a foot lever. If a single blow is desired, the treadle is depressed and released at once; the hammer will then fall, rise to its top position and stop. If a succession of blows is desired, the treadle is held down and the hammer will continue to operate automatically until the treadle is released. Clear, straight-grained maple, free from all knots, is the only material which will stand up under the severe

FIG. 22. MEDIUM-SIZED BOARD DROP HAMMER
Chambersburg Engineering Co.

crushing pressure of the rolls. It is expensive and difficult to obtain, and many attempts have been made to substitute paper, fibre, and other materials, but nothing has as yet proven satisfactory. One of the rolls in the head is carried in fixed bearings and the other roll is mounted on an eccentric bearing operated by a latch rod. The raising or lowering of the latch rod rotates the eccentric and presses the movable roller in and out against the board. The rollers are driven by pulleys and rotate continuously.

The weight of the base of a drop hammer should be from 12 to 20 times that of the head, as a heavy base will increase the size of the forging work which may be done for a given weight and fall of hammer head. Board drops, as in the case of steam hammers, are rated by the weight of the head, which runs from 200 up to about 3,000 pounds. The board and friction rollers are not practicable for weights beyond this, and the larger sizes of drop hammers, which range from 3,000 as high as 12,000 pounds, are operated by steam. The steam drop hammer is essentially the same as the board drop except for the lifting mechanism. It corresponds to the first type of steamer hammer mentioned on page 88, except for the general design of the frame which conforms to that of the board hammer.

Trimming Press.—It is impractical to guage exactly the amount of metal necessary to fill the impression. To make sure that it is filled, an excess of stock is always provided which is allowed to go off sidewise into a space provided between the surface of the dies. The fin, or flash, which results must be

trimmed off. It is cheaper to trim forgings cold after the whole run has been made, but this can only be done on small work, as the flash is thin and chills quickly and retards forging. For large work, therefore, to allow the hammer to expend its energy on the forging and not the flash, a trimming press is installed at the side of the hammer and the forger will step over to the press and trim the forging once or twice during the progress of the work.

Dies.—The dies for drop hammers are rectangular blocks which, for general all-around work, are made of 60-point open-hearth steel. By "60-point steel" is meant one having six-tenths of one per cent of carbon. If a large number of tool steel forgings are wanted, 80 to 90-point tool steel is better; and for the severest use 3½ per cent nickel steel may be used. Sometimes cast iron is used for large work where there are not many pieces. It has been considered treacherous material for dies and is only used because the impression could be cast in the face and little finishing work is required.

Recent experiments have shown cast iron dies in a more favorable light. They are made of a special mixture of high-grade iron. In molding, "a core is made of the impression pattern to withstand the weight of the iron and consequent crumbling, which ordinary sand could not do. The molding flasks are in three parts—the 'drag,' containing the core and plaster pattern; the middle part, holding the block pattern, and the 'cope,' the wood pattern of the tongue or shank. Instead of pouring the molten iron through the top, a special inlet is made through the

sand and to one side of the mold, allowing the iron to run out gently over the core instead of falling onto it. In this way the mold is filled from the bottom up, making possible the casting of delicate impressions without fear of breaking the sharp corners. A riser is left in the top of the mold providing for the shrinkage of the cooling iron and for bringing the 'slag' to the surface. All that remains to be done to prepare the castings for the hammer is to clean out the impressions with a brush or die and to stamp them with their designating numbers."* The reports of these dies show a saving in time and expense. "The maximum time required to turn out cast-iron dies ready for the hammer is four days; the average time for steel dies is between one and four weeks. * * * In many cases the life of the dies nearly equals the average duration of steel dies. Even if cast-iron dies did not produce one-third as many forgings as steel dies, the saving in cost would be sufficient to justify their use, letting alone the time saved."

The backs of dies, where they are secured to the base and to the hammer head, are provided with dovetailed shanks which slide into corresponding grooves and are then tightened with a taper key driven in by a sledge. In selecting the size of the die blocks sufficient metal should be left around the impressions to make sure that the die will not split. For ordinary work 1½ inches is enough. The depth of the blocks runs from about the same as the width to about ¾ or 2-3 of the width; for wider blocks the

* American Machinist, October 12, 1916.

depth increases. A die 14 inches wide would be about 8 inches deep. The length varies with the forging to be made.

Die Working.—The first operation in preparing the blocks is that of planing the edges square and true, as the impressions are located from the edges. The blocks are then turned over and the shanks cut. So far as possible the size of shanks should be standardized to insure interchangeability of use in the various hammers available.

Before laying out the impressions one or more templates are made of sheet steel, the principal one giving the contour of the forging along the parting line of the dies. Other templates are made of the cross sections at various points. These templates must allow for the shrinkage of the forging, for any extra stock to be machined off later, and for draft. Draft is a taper of not less than 7 degrees on all straight sides of the forging so that it may be freely lifted out of the die. Without this draft the forging is liable to stick and give trouble. If possible the draft is put on surfaces which are to be machined, as it then disappears in the finished piece. More draft should be allowed for an internal surface, as shown in Figure 23, than for an outside one, as the metal in shrinking tends to seize the sides of a plug in the die while it tends to free itself from outside surfaces. The choice of the best parting line is a matter of skill and experience. Often a curved surface is used which follows an available line in the forging, as the butt plate for a rifle shown in Figure 24, and the receiver shown in Figure 26. This is

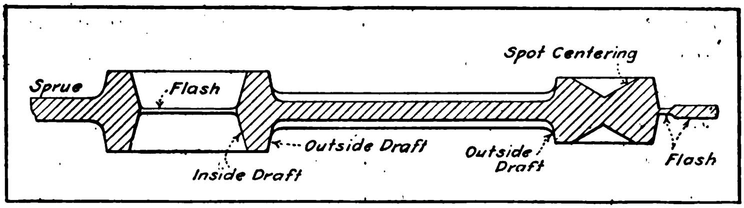


FIG. 23. LONGITUDINAL SECTION OF A DROP FORGING FOR A CONNECTING ROD PRIOR TO THE TRIMMING OPERATION

necessary in bent pieces, as the forging must in all cases lift out of both dies freely.

Having determined the parting line, the faces of the die are planed, and the impressions are laid out with the aid of the templates. The impressions in the two dies are right and left-handed, so that they will match when the two faces are brought together. The number of impressions required depends on the size and

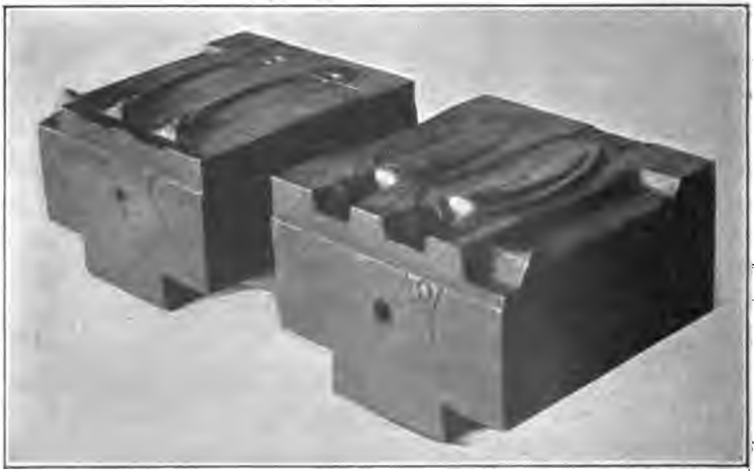


FIG. 24. DIE BLOCKS FOR THE BUTT PLATES OF A RIFLE SHOWING INTERLOCKED DIE

character of the forging. In general there is a roughing and a finishing impression, and an "edger" or side breakdown. The last is very important, as its function is to work the material of the bar stock, from which the forging is made, into its proper location and to bend it into something like the final shape so as to relieve the forging impressions of as much wear as possible. Fullers, or flat places milled near the side of the blocks, are used for drawing out the stock. In Figure 25 the first view shows a piece of the original bar stock and the second is the piece after the fuller has drawn it out and the edger has bent it. The metal is then substantially in place, ready to be placed in the forging impression.

After the forging impressions have been cut, the surface of the die is milled off to a depth of about 1/32-inch for a width of ¼ to ½-inch, beyond which it may be deepened a little to provide space for the flash. The flash is trimmed off during or after the operation. The thin portion of the flash next to the forging facilitates the work of trimming.

The "sprue" is a neck connecting the forging with the bar from which it is made and by which it is manipulated during the operation of forging. This is formed by a groove which is cut from the end of the impression out to the edge of the die block. A knife, in the shape of two sharp cutting edges on the corner of the dies, is sometimes provided to cut off the sprue when the forging is completed. Where there are many pieces and the impressions are small enough to permit it, several forging impressions may be cut on the face and are used progressively. The last im-

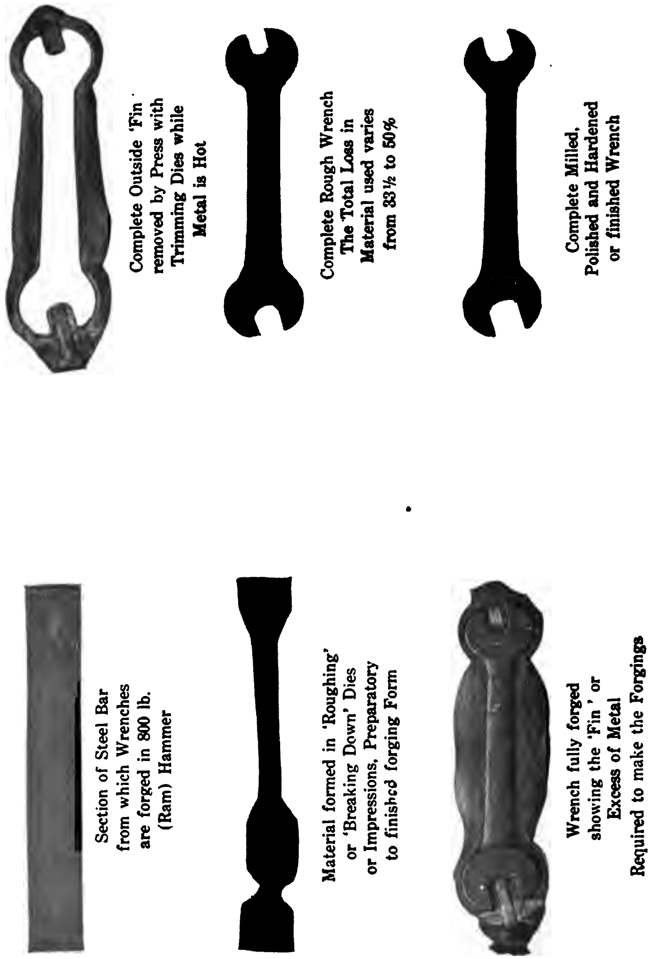


FIG. 25. STAGES OF A DROP FORGING

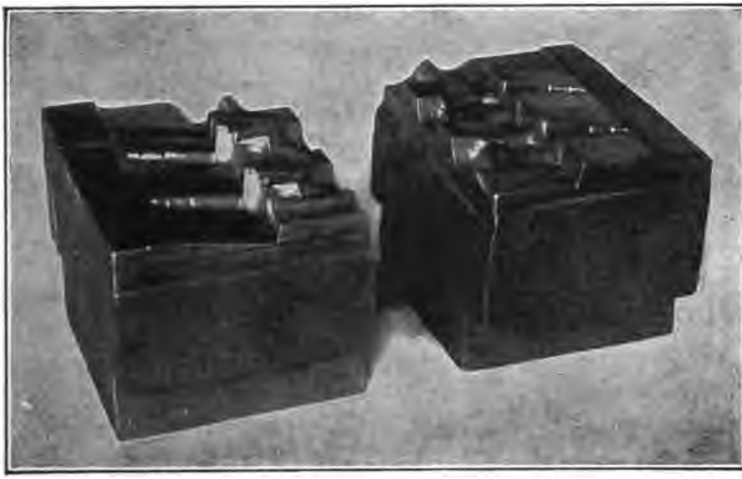


FIG. 26. DIE BLOCKS FOR A SHOT GUN RECEIVER, SHOWING INTERLOCKED DIES

pression is used only to give the final blow and bring the work to size. Letters may be cut in this impression so that the forging bears some desired marking, such as the maker's name, the size, or part number. By the time the forging has reached this last impression it has assumed almost its final shape and the only work to be done is to bring out sharply the details, such as the lettering referred to. By this succession of impressions the last one retains its accuracy a long time. The side impressions used for the preliminary work are called the "breaking down" impressions, and the upper ones "finishing" impressions. The impressions will, of course, wear out. This appears by the rounding off of corners, and the gradual widening of the impression and loss of definiteness. The dies may sometimes be re-faced and re-cut.

Often they fail by cracking or splitting, which precludes their further use. After dies are cut they are usually hardened on the face and shanks, as these are the two portions subject to wear. Some makers, however, have the shanks soft and claim better results against breakage. It is desirable that the main portion should be as tough as possible and consequently these are left unhardened. In order to insure the registering of the two impressions they are accurately located with reference to the planed edges. When the dies are set in the hammer they are lined up by these edges and it is then known that the position of the impressions is correct.

Heating.—In heating steel for forgings, the temperature should be raised slowly to about 600 degrees Fahrenheit, and after that it can be raised as quickly as desired to the welding temperature. This is due to the fact that steel is not ductile below about 600 degrees Fahrenheit, and is not fitted to resist the strains imposed upon it by the differential expansion of an unevenly heated metal.

By heating suddenly, the outer shell becomes red before the core has had an opportunity to absorb any heat, and great strains are thus caused by the expansion of the outer shell. Due to these changes when heating up cold steels and especially the high-grade alloys, many poor forgings are turned out by raising the temperature of the metals too suddenly.

The Forging Operation.—Drop forgings are made from forging bar stock cut into convenient lengths to make a certain number of forgings and heated usually in gas or oil furnaces. When ready for forg-

ing the heated end of the bar is placed under the hammer, drawn out, if necessary, on the fuller, and bent into the approximate shape on the edger. It is then laid over on the face of the die on the forging impression and the forging work is performed. As the metal is brought to size the flash begins to appear and, in the case of large forgings, is trimmed off as the work progresses.

The number of blows required varies with the size and shape of the work. Small and simple work may be forged in one or two blows, while large work will require many. Thin sections require a larger hammer and more blows than a thick or chunky one, as the hot metal is exposed to the cold surface of the dies and chills quickly. When the forging is finished it is cut off at the sprue and drops out on the floor, while the bar is returned to the fire for reheating.

Pickling.—After the forgings are made they are pickled by dipping in dilute sulphuric or hydrochloric acid and rinsed off in hot water. This operation is similar to that already described for castings in foundry work.

Cold Trimming.—Small forgings are always trimmed cold, as it is much faster and cheaper than hot trimming. This work is done in stamping presses and the forgings may be handled by hand. Trimming dies have the form of the forging around its parting line. For ordinary work they are flat with their cutting edges in one plane. The trimming dies for forgings having an irregular parting line must be bent to conform with the surface of the forging dies. If the piece is to have a hole in it, the flash which

closes this hole must be trimmed separately from the flash on the outside. Forgings, like castings, are subject to shrinkage, and consequently the size of hot trimming dies must be larger than the finished work for they do their work before the shrinking has taken place, and the parting template used to lay out the forging dies may be used to lay out the trimming die. Cold trimming dies are the size of the finished forging. The steel for the trimming dies is usually 60 to 70-point carbon tool steel, hardened and tempered, while the punch may be low carbon steel as it has merely to push the forging through the die, the lower end being shaped to fit over the forging like a saddle. Trimming dies are usually sectionalized or made in a number of pieces fitted together and mounted on a plate. This is to permit regrinding when necessary. Otherwise the size when once lost could not be restored.

On account of the shrinkage forgings will inevitably distort somewhat in cooling. If they are restruck when cold, in dies accurately cut for that purpose, certain dimensions may be brought to within .001 or .002-inch of specified size. Consequently this work is sometimes done when great accuracy is required, or to straighten forgings bent during the trimming.

General Considerations.—The range in size of drop forgings is from small pieces the size of a thimble to pieces weighing 100 or 200 pounds. The process is limited in its application by the cost of making dies, and these are justified only for a comparatively large number of pieces. Where forgings are to be drilled

later at right angles to the parting plane, the holes may be located quite accurately in the drop forging by what is known as "spot centering," whereby conical depressions are formed at the spot where the hole is to be drilled, acting as a starting point for guiding the nose of the drill. Frequently drop forgings are forged in one plane and then bent in a subsequent operation. A conspicuous example of this is that of six-throw cranks for automobile engines. These are forged with all the cranks in one plane, and the shaft is then twisted in a subsequent operation so that the cranks will stand at the required angles. Frequently when the forgings are small and simple in shape, two or more may be forged at once. The dies in this case will correspond to a foundry mold made from a gated pattern.

CHAPTER IX

WELDING, SOLDERING AND BRAZING

General Classes of Welding.—Welding, as a branch of blacksmithing, is a very old process—a general outline of smith welding was given in the chapter on Forging. Of recent years new methods and machines have been developed which have enormously increased the importance of welding and extended its use.

Welding is the uniting of metals into one piece or mass by hammering, pressing, or casting them together while in a heated condition. Soldering is the uniting of two pieces of metal with a third metal applied in a molten state. Brazing, really a form of soldering, is the uniting of two pieces of metal by a thin film of soft brass. These processes run into each other more or less. Two unlike metals such as iron and platinum may be welded, while two pieces of steel may be united by placing platinum foil between them, pressing them together, and heating them. While this is strictly welding, yet the platinum foil acts as a solder.

There are two general classes of welding: First, pressure welding—which includes both hand and steam-hammer work on wrought iron and steel—and electric resistance welding, known as the Thomson

process; and second, welding by casting, which includes electric-arc, gas-flame and thermit welding.

Welding under pressure is a mechanical process, not a chemical one, and depends upon the plasticity or flow of the metal as well as upon the wetting or cohesion of the two surfaces at welding heat. The latter can occur only when the two metallic surfaces are in absolute contact. The interposition of any foreign substance, such as a film of oxide which cannot be pressed out by hammering or other means, precludes welding. As pointed out on page 87, the only use of flux is to form a fluid slag by chemical combination with the oxide which can be pressed out and allow the two surfaces to come into actual contact. For ordinary purposes pressure welding must be done in a few second's time, and the previous cleaning and heating must not take long. Were it not for the electric arc, oxy-hydrogen, oxy-acetylene, and thermit processes, commercial welding would be confined to wrought iron, steel, nickel, and the precious metals.

The term autogenous welding, as applied to the electric-arc and gas-flame methods is a misnomer, since it means self-welding. Fusion welding would be a more accurate word as the extremely high temperature of the flame melts the metal locally, causes it to form its own solder, and in reality casts it together.

Pressure Welding by Hammering.—What is known as welding-heat varies with different compositions of metals from dark red, or about 700 degrees centigrade, to dazzling white, about 1,500 degrees. As

already pointed out (see page 87) the material must be heated cleanly in a reducing fire, and the surfaces must be shaped or prepared for the joint. As the strength of a welded joint is less than that of the stock itself, the joint is usually made on an angle. Scarfing the joint at an angle strengthens the joint by increasing the welding surface, and makes it easier to apply the heavy pressures necessary to bring the surfaces into contact. In general, large welds are unreliable, as it is difficult to insure perfect contact over all of the surface to be welded, and for this reason steel castings are superseding built-up forgings for large pieces such as ships' frames, rudder posts, and locomotive side-frames.

Copper is weldable by pressure; it is not often welded in this way, however, since soldering or brazing is preferred. To weld copper the metal is heated to redness, calcined flux containing borax and a phosphate salt is sprinkled on the surface, and the pieces are joined at a yellow heat and hammered together, as in iron-welding. Copper may also be welded by the electric process. Aluminum may be pressure-welded, but it is not easy to keep the ends free from oxidizing. The usual method of welding is by the oxy-acetylene process, described later. Platinum, gold, and silver may also be welded, but need not be considered here.

Many manufactured products are based on the process of welding. The oldest of these are welded pipe and chains. Pipes are made from long, thin strips of wrought iron or steel known as skelp. The strips are curled up into tubes by drawing them

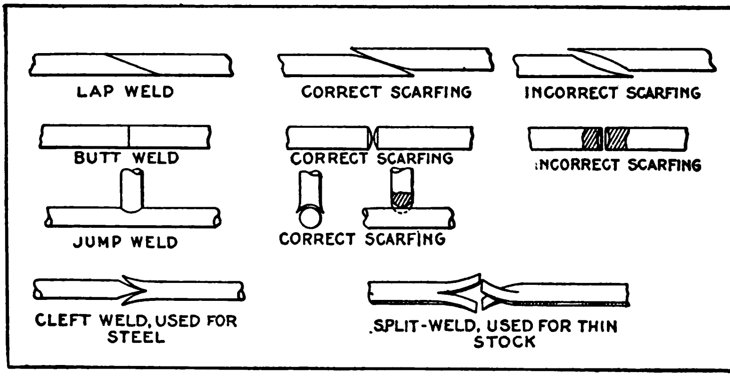


FIG. 27. TYPES OF WELDS WITH CORRECT AND INCORRECT SCARFING

through circular dies. The two edges are brought together and welded, in the case of butt welds, by being drawn through the annular opening between a mandril and a circular die slightly smaller in size than the outside of the pipe, which produces the pressure necessary to make the weld. In the case of lap or scarf welds a roll is also used to press the joint down against a mandril or bar inside the pipe. Welded pipes are made in commercial sizes of from ⅛-inch to 30-inch internal diameter. Beyond this size they are generally riveted. High carbon steels cannot be used for pipe, as they weld so poorly that the high strength of the material is offset by the uncertainty of the weld. Chains are still welded largely by hand, although small chains are now made automatically in electric machines of the Thomson type. For small sizes the links are cut from spirally wound bars, heated in a gas oven, and swaged or scarfed by a hydraulic press with a die of suitable shape. The

steel for chains must be pure, and low in carbon. With chains, as with pipe, the strength depends mainly on the perfection of the weld, and good practice limits the load to 50 per cent of the working tensile strength of the material. For manufacturing purposes electric resistance welding and the various forms of fusion welding are generally more efficient than smith welding.

Electric Resistance Welding.—There are two clearly defined types of electric welding—resistance and arc welding. Resistance welding was invented by Elihu Thomson in 1877, and has been used commercially since 1880. In this process a large volume of current at low voltage is forced through the work and across the joints to be welded. The heat developed at the point of contact, which is the point of highest electrical resistance, raises the temperature of the material quickly to a welding heat. At the same time the pieces are pressed together by heavy mechanical pressure, which forces the softening surfaces together so that complete contact is effected. The metal can be raised to the temperature desired, and the heat can be held for any length of time and increased or decreased at will.

The elements of the apparatus are (1) a supply of alternating current from a generator or power service system; (2) a step-down transformer, usually carried in the body of the machine, to lower the voltage; (3) apparatus for regulating the current, sometimes arranged to shut off the current automatically as soon as welding heat is reached; (4) clamps for holding the metal to be welded and transmitting

the current to it; (5) means for forcing the two sections together. Machines embodying these elements are built in a wide variety of sizes and types suited to the kind and section of metal to be welded. One of them is shown in Figure 28.

The following table shows the power and time required to make welds of various sized sections in iron and steel:

TIME AND POWER REQUIRED IN ELECTRIC RESISTANCE WELDING*

Diameter Inches	Area in Square Inches	Kilowatts, Transformer	Seconds To Make Weld	Cost per 1000 Welds at One Cent per Kilowatt Hour
1/4	0.05	5	5	$ 0.07
3/8	0.11	7 1/2	6	0.13
1/2	0.20	8	10	0.22
5/8	0.31	10	12	0.33
3/4	0.44	12	15	0.50
7/8	0.60	15	20	0.83
1	0.79	18	30	1.50
1 1/8	0.99	20	30	1.66
1 1/4	1.23	26	40	2.89
1 1/2	1.77	40	60	6.67
1 3/4	2.41	45	70	8.75
2	3.14	56	80	12.44

The Thomson process has many advantages. The operation, as seen from the table, is very rapid. Even as many as twenty welds may be made in a minute. In chain-welding ten links a minute can be welded, of the smaller sizes. The heating is even, local, and under perfect control. There is little danger of ex-

* Machinery's Reference Book No. 127, p. 21.

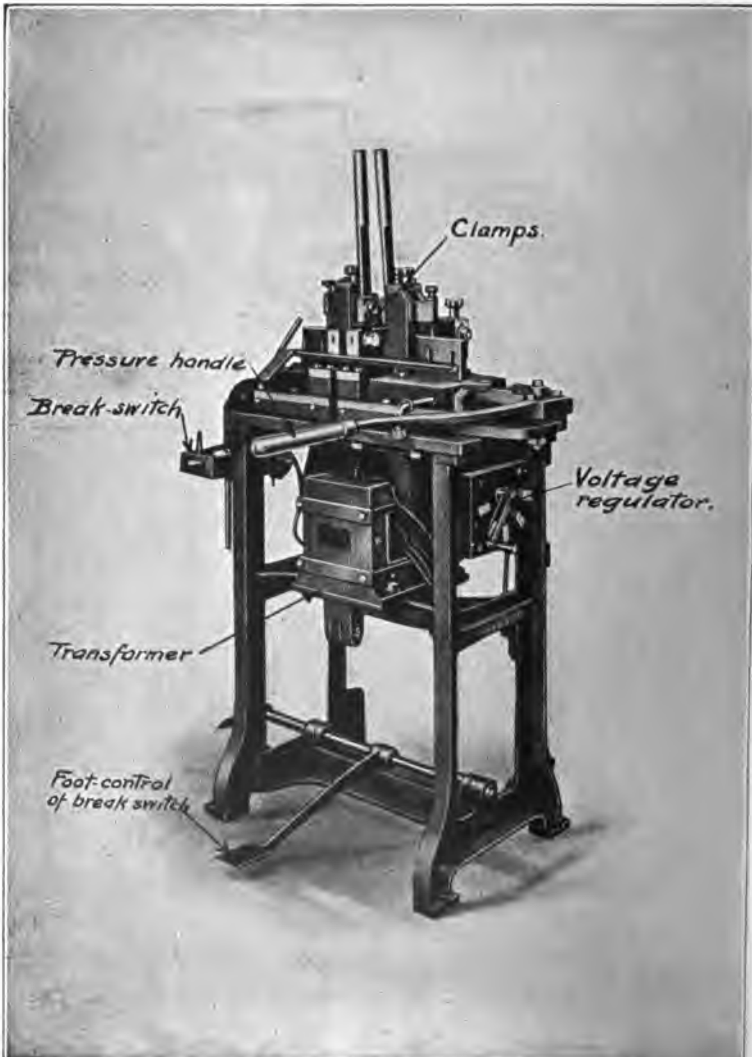


FIG. 28. THOMSON BUTT-WELDING MACHINE

cessive heating, as there is with the arc and gas-flame methods, consequently there is very little oxidation or decarbonizing of the material. Practically all the heat generated goes into the weld, and is so low that the whole process can be watched with the naked eye. Arc and gas-flame welding require glasses and a hood to protect the operator's eyes from the blinding light, and this hood necessarily is a hindrance to the worker.

The clamps that are used for forcing the pieces together may be machine-operated and accurately alligned, so that the locating of the parts during the weld may be very close. There is a high power efficiency amounting to 75 per cent and over. The power is used only as long as needed, and may be turned off instantly. Since the heating is local and moderate, finished or nearly finished work may be welded with little or no damage. Finally, the apparatus can be operated by even a moderately skilled workman with little danger.

The method has been applied successfully to welding more kinds of metals and combinations of metals than any other process, as may be seen by the list on the following page.*

The Thomson process is better adapted to "repetition" work—to performing the same operation many times—than to doing special or job work. The apparatus requires a more or less elaborate machine, not easily portable, and is therefore not so good for general outside work as gas-flame welding. It demands a large amount of power at irregular intervals,

* Modern Shop Practice, Vol. II, p. 239.

METALS

Wrought Iron	Lead	Antimony	Bismuth	Platinum
Cast Iron	Tin	Cobalt	Aluminum	Gold (pure)
Copper	Zinc	Nickel	Silver	Manganese

ALLOYS

Brass	Nickel Steel	Crescent Steel	Aluminum Bronze
Solder	Gun Metal	Bessemer Steel	Phosphor Bronze
Stub Steel	Fuse Metal	German Silver	Brass Composition
Coin Silver	Type Metal	Silicon Bronze	Various Tool Steels
Gold Alloy	Chrome Steel	Aluminum Iron	Various Mild Steels
Cast Steel	Mushet Steel	Aluminum Brass	

COMBINATIONS

Copper to Brass	Wrought Iron to Tool Steel
Copper to German Silver	Wrought Iron to Mushet Steel
Copper to Gold	Wrought Iron to Stub Steel
Copper to Silver	Wrought Iron to Crescent Steel
Tin to Zinc	Wrought Iron to Cast Brass
Tin to Brass	Wrought Iron to German Silver
Tin to Lead	Wrought Iron to Nickel
Brass to German Silver	Mild Steel to Tool Steel
Brass to Platinum	Nickel Steel to Machine Steel
Brass to Tin	Gold to German Silver
Brass to Mild Steel	Gold to Silver
Brass to Wrought Iron	Gold to Platinum
Wrought Iron to Cast Steel	Silver to Platinum
Wrought Iron to Mild Steel	Steel to Platinum

and for this reason may give trouble on the electrical-supply lines from which the current is drawn. These disadvantages, however, are not serious, and for manufacturing work this method of welding is one of the most useful that has yet been developed. It has been extensively used in the manufacture of bicycles, automobiles, typewriters, chains, wire fences, rakes, and railway cars, and in spot welding of all kinds. It is particularly good for small butt welds. The strength efficiency of the weld is very high, running from 75 to 95 per cent, and even over 100 per cent

when the upset resulting from the weld is not cut off, which means, of course, that the material when broken will part in the original stock and not at the weld. In welding chain, from 10 to 30 per cent of the current travels around the link instead of across the joint. This loss of current is expensive, and constitutes one of the reasons why hand welding still holds its place in the trade. The loss of current is less for large rings. Garden rakes, which used to be castings, are now made by jump-welding the teeth on to the crossbar. Rail-welding was first done by this process, and special machines have been developed for this particular kind of work.

La Grange-Hoho Process.—The La Grange-Hoho or "water pail" process is in fact merely electric heating. The process originated in Belgium, and has not as yet found much use in this country. The pieces to be heated are fastened to the negative pole of the circuit and immersed in an electrolyte bath, such as potassium carbonate solution. As the current flows from the positive pole through the solution and into the metal pieces, the solution begins to decompose and deposits a thin film of hydrogen about the pieces, protecting them as they become hot. As soon as the welding heat is reached, the pieces are withdrawn from the solution and welded between the hammer and the anvil in the usual manner. The advantage of the process is that the metals are cleansed from grease and dirt by the bath, and are protected from oxidation during the heating by the hydrogen film. The heat, however, is not very easily controlled, and the hot metal will oxidize in the air when taken

out just as quickly as if it had been heated in a forge fire.

Electric-Arc Welding.—The three best known systems of electric-arc welding are the Zerener, the Bernardos, and the Slavianoff. In the Zerener process there are two carbon electrodes mounted in a frame that holds them pointed towards each other and toward the work. The electric arc between them is deflected by a magnet and used in the same way as a gas flame. Welding material is furnished in the shape of a melt bar. The apparatus is bulky, more or less complicated, cannot be used with large amounts of current, so that it is limited to use in comparatively light work. The advantage claimed for this system is that the arc may be controlled by the magnet, and consequently fine work can be done.

The Bernardos system allows for the production of an electric arc between a carbon negative electrode and the material to be welded. Welding metal is furnished by a melt bar. Direct current is used. While any metal which does not volatilize or burn too easily may be welded by the Bernardo process, it is best adapted for use with cast iron, copper alloys, and aluminum. When the graphite pencil is used, a rotary motion is given to it which causes the arc to play over the surface of the job, distributes the heat evenly, and prevents burning. This motion also drives the slag or impurities off to one side and away from the weld. The adaptation of the Bernardos arc to cutting is of recent date. When used for cutting, the arc begins at the top and moves downward across the face of the piece. It is not so efficient for this

purpose, however, as the gas flame, which makes a cleaner and smaller cut and clears away the metal as the flame advances.

In the Slavianoff process the welding heat is produced by an arc between the melt bar, or welding metal—which forms the negative electrode—and the metal to be welded. Continuous current at a low voltage is used. After the arc has been established by touching the electrodes together and separating them, the welding pencil begins to melt and furnishes the filling material. This system has been more successful with iron and steel than with other metals; its main application has been in sheet-metal work, the metal electrode being deposited along the joint to be made. The current required for this Slavianoff process is much less than that for the Bernardos process, but its action is much slower for operations requiring the deposit of large amounts of metal. Probably, however, it is the most successful of the arc welding processes.

All three of the arc welding methods are used on large and varied kinds of work, such as jobbing work, repairs, and so on. The temperatures in the arcs are unknown, probably ranging from 5,000 to 7,000 degrees Fahrenheit, which is far above the melting point of any metal. A skilful operator is required, and great care must be used to avoid over-oxidation and burning away of the metal. As with the gas-flame methods, the light produced is blinding to the naked eye and the workmen must be protected by hoods or glasses, which more or less hamper manipulation.

Gas-Flame Welding.—These forms of welding usually take their name from the gases used, as oxy-acetylene, oxy-hydrogen, and so on. The oldest of these uses an oxy-acetylene torch which is practically a blowpipe that burns acetylene gas and oxygen. As first applied, these gases were used under high pressure; later, low pressure systems were developed and now the danger that attended the process in its earlier years has been largely eliminated. Figure 29 shows the connections of a typical torch with a section of the nozzle. The utility of the torch comes from the high temperature of the flame, which ranges from 6300 to 7000 degrees Fahrenheit, and which is able to bring the part of the metal acted upon to a molten condition before the heat can be radiated or conducted away. This makes possible welding through local recasting, and also cutting by burning a section across the piece to be parted. In welding it is usu-

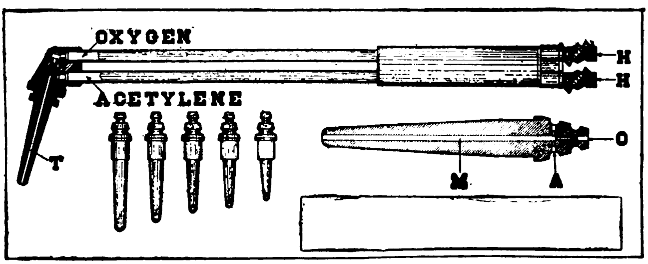


FIG. 29. OXY-ACETYLENE WELDING TORCH AND TIPS
Davis-Bournanville Co.

H, H, Hose connections, with needle valves, for oxygen and acetylene. T, Removable welding tip—five tips are furnished for varying pressures and different thicknesses of metal. O, Oxygen inlet. A, Acetylene inlet, from both sides at right angles to oxygen inlet. M, mixing chamber in tip.

ally necessary, except in the case of very thin sheets, to add metal to the joint. This is melted in from a welding stick, or melt bar, of the same material as the pieces to be welded. If the metals joined are dissimilar, a stick of material carrying the same elements but melting at a lower temperature should be used. The flame should be large enough to heat the metal in the shortest possible time with a reasonable consumption of gases. Ordinarily the flame is manipulated by hand, but recently various forms of apparatus have been developed which provide machine control for the flame, so that it may be accurately directed in a definite path. This is especially useful in cutting and spot welding.

In cutting work an additional jet of oxygen under pressure is fed into the flame. The flame proper raises the temperature of the metal far above the melting point; the excess oxygen furnished by the second jet unites with the metal and it is literally burned, not melted, away. The cutting speed and the penetration of these torches is remarkable. An oxy-acetylene torch will cut steel 12 to 15 inches thick, and a hydrogen torch has cut metal 24 inches thick.

The principal elements of an oxy-acetylene installation are the apparatus generating or storing oxygen, the apparatus generating or storing acetylene, and the torch with its connections. Acetylene gas is a chemical compound of carbon and hydrogen, formed from the reaction between calcium carbide and water. Calcium carbide itself is not explosive when dry. It has, however, a great affinity for moisture, and the gas generated is explosive. It is therefore stored in

air-tight cans. For large plants the oxygen may be generated profitably, but for small plants and portable work it is purchased in steel tanks. The acetylene is generated in small quantities as used. The generator is a steel receptacle for holding the gas, with various attachments for controlling the action of the water on the carbide.

The hydrogen used in oxy-hydrogen flames may be obtained from the decomposition of water into oxygen and hydrogen, both gases being collected and used, or it may be formed by passing steam over coke. It is, however, usually purchased in heavily charged tanks. The oxygen used is produced commercially by three methods: from the air, by liquifaction and distillation; from water, by electrolytic action; and from potassium chlorate. The first of these methods is the most important commercially. Although the production of oxygen is not a complicated process, the apparatus is rather expensive and its use is justified only when the quantities used are rather large. Oxygen is sold in tanks containing 5, 25, 50 and 100 cubic feet.

Two kinds of acetylene generators are used, known as the water-to-carbide, or water feed, and the carbide-to-water, or carbide feed. The first is little used, because the apparatus may get hot and be a source of danger. When the second method is used, powdered or granular carbide is dropped into the water; the gas is washed as it is evolved, and the apparatus is kept cool. Furthermore, water-feed generators give off gas long after the water is stopped, but the carbide feed gives off gas only for a short time after-

ward. Generally about a gallon of water is used for each pound of carbide—one pound of lump carbide will generate 4½ cubic feet of gas.

Advantages.—The advantages of gas-flame welding are that the apparatus required may be either light and easily portable, or may be installed permanently. For repair work, the gas flame shows low cost and excellent results. The improved methods of controlling and guiding the flame have extended the use to manufacturing work, in which it is competing actively with the Thomson process. Owing to the high heat of the flame, any metal can be melted locally at once if desired. Its disadvantages are similar to those of the electric arc, in that a skilled operator is required and he must use a hood and glasses to protect himself from the intense brightness of the incandescent metal. Furthermore, as the weld is a melt weld in the open air, it is subject to more or less oxidation.

Uses.—The gas flame is used for welding wrought iron, cast iron, and steel, for mending cracks and blow holes in castings, and for all kinds of repairs on iron and steel. Recently it has been applied successfully in spot welding in the manufacture of metal goods. It has been widely used in cutting work of every kind, such as the removal of sprues and risers from steel castings, cutting up scrap, and heavy salvage work of all kinds.

Thermit Welding.—Thermit welding was invented by Dr. Goldschmidt, of Essen, Germany. By this process a mold, usually of refractory clay, is built around the parts to be joined, and finely divided iron oxide

and powdered aluminum are poured into the mold and burned. A chemical reaction follows which produces pure iron and aluminum oxide. The temperature of the reaction is about 5400 degrees Fahrenheit, or nearly 2000 degrees above the melting point of iron and steel. The iron formed by the reaction makes a superheated bath around the joint. The ends of the work which are to be joined are therefore melted, and fuse with the molten metal in the mold, while the aluminum oxide formed rises to the top of the molten mass and is skimmed off. When the reaction is over, the whole cools into a solid mass.

The thermit process is obviously applicable only to iron and steel, as it involves a chemical reaction with iron. Its advantages may be summed up as follows: first, the apparatus is simple; second, high skill is not needed to do the work; third, it is possible to repair breaks difficult of access and to mend broken parts where they are which otherwise would have to be taken out; fourth, local heating is possible on a larger scale than is possible with the gas flame. The thermit process has been used successfully in welding rail joints, and forms of molds have been developed specially adapted to that work. The process is adapted only to rough and large work, and is too cumbersome for general use in manufacture where the Thomson process and the gas flame have been successful. For pieces below four square inches in cross section, other processes are better. Some wonderful repair work has been done with this process in the welding of ship frames, rudder posts, and so on. The breaking strength of a thermit weld runs

about 60,000 pounds a square inch. If the reinforcement can be left on the weld, it will have a greater strength than the original material; if it is machined off, it will have about 80 per cent of the original strength.

Soldering and Brazing.—Soldering and brazing differ from welding in the use of a separate material which is used to make the joint. The material used for the solder must be such as will actually wet the surfaces or amalgamate with the pieces to be joined. An alloy of lead and tin is generally used, although special solders are made without either of them. Soldered joints are not as strong as welded or brazed ones, because the strength is limited to that of the soldering material, which is almost always lower than that of the other metals. The process requires less heat than welding or brazing, is easily performed, and requires almost no apparatus. An ordinary gas flame or blow pipe may be used. For work of moderate size a gasolene or kerosene torch may be employed; electric heating irons are frequently used for running in the solder. The common fluxes are sal ammoniac, zinc chloride solution, rosin and alcohol, and borax. These are used to dissolve any grease and to remove any oxide present, and they leave a clean surface for the solder to wet. Most solders melt at about 400 degrees Fahrenheit—soft solders at 350, and hard solders at about 625 degrees. The soldering process consists of scraping the surfaces clean, heating them to the soldering temperature by any suitable means, fluxing the surfaces to be joined, melting the solder into the joint, and finishing off the joint after

it has cooled. The most important requirements are to watch the temperature and the flux. Too high heat causes oxidation and makes the solder run too freely; poor fluxing prevents the solder from amalgamating with the pieces to be joined. Nearly all the metals except aluminum are soldered commercially. The process is used only for small work and on joints which do not have to carry a heavy strain.

Brazing Process.—This process is similar to soldering, the main difference being the use of a harder filling material, which requires a higher melting temperature. Iron, copper, and brass may be brazed. Brazing alloys—or spelters, as they are called—are mixtures of copper, zinc, and tin. The composition varies with the nature of the work; the hard spelters give a stronger joint, but require a higher temperature. The flux used is made of borax or boracic acid, and the heating apparatus usually takes the form of a gasolene or kerosene torch for small and moderate-sized work. A blacksmith's fire may be used, but care must be taken to keep the parts from touching the fuel, and a reducing flame is necessary since the work is done at high temperature. Iron and steel require a high heat, for which a blue Bunsen flame is generally used.

In brazing, the surfaces must be cleaned by scraping, washing and brushing, then the flux is applied, and the pieces are clamped in position ready for joining. The heating should be gradual and well distributed. The spelter, which is melted in when the proper temperature is reached, will flow into the space left between the parts and make a tight joint. After the

operation is completed, the pieces should be allowed to cool slowly. For large quantities of work, immersion brazing is used, which consists in cleaning and fluxing the parts, clamping them together, and dipping them into a tank of molten spelter. Brazed joints, when well made, may be as strong as the original metal, and while they are not so good as welds they are cheaper and easier to make. When used in manufacturing processes, special holding devices may be employed, which greatly facilitate the work. Brazing is used widely for small joints, and is a reliable commercial process.

CHAPTER X

HEAT TREATMENTS

Variability of Steel Properties.—The physical properties of steel, such as hardness, strength, and toughness, may be varied to suit particular needs to a degree possible with no other material. We are so used to the marvel of easily and accurately cutting a piece of steel with an edged tool made from the same bar that we do not appreciate it. A railroad rail, the rudder post of an ocean liner, a watch spring, and a razor are composed, in the main, of the same material. The difference in their properties is due to the presence of certain alloying constituents and to the heat treatment to which they may have been subjected. These two factors are closely inter-related. Heat treatment consists of heating and cooling the metal through certain temperature ranges and with certain rates of temperature change. Of the various metallic materials, steel offers the widest variation of physical properties through heat treatment. The capacity so to manipulate it depends upon both the kind and the percentage of alloying constituents. Pure iron cannot be hardened.

The principal alloying element in steel is carbon, and steels which contain only carbon as a useful element are called carbon steels. The percentage of car-

bon present forms the basis for commercial classification. Below 0.15 per cent the material may be either steel or wrought iron, according to whether it was, or was not, molten in the early stage of its manufacture. Steel which contains from 0.15 to 0.35 per cent of carbon is known as machinery steel; from 0.35 to 0.60 per cent, as open-hearth steel; and from 0.60 per cent up to a maximum of 2 per cent, as crucible or tool steel. Other elements—such as sulphur, phosphorus, and silicon—may be present in small quantities, but constitute undesirable impurities. Manganese is also present, and up to a certain limited percentage is a desirable element. Carbon steels are referred to as twenty point or thirty point, according to the number of hundredths of one per cent of carbon present. In general the strength of steel rises with the increase in the carbon. Ten-point steel is nearly 25 per cent stronger than pure iron, and through a considerable range the tensile strength rises about 2½ per cent for each point of carbon added. Of recent years there has been rapid development of steels known as high-speed steels, for cutting purposes, which derive their properties from the addition of other elements, such as chromium, tungsten, vanadium, molybdenum, manganese, and nickel. Since, however, their composition and treatment are too complex to be discussed here, this discussion will be confined mainly to a consideration of carbon steel.

Heat Treat Processes.—There are the following four well-known forms of heat treatment:

1. Hardening, which consists of heating the steel

to a certain temperature and quenching it suddenly in some cooling medium. This process is used to produce very hard wearing surfaces, and the cutting edges of tools.

2. Annealing, which is similar to hardening, except that the steel is cooled slowly instead of suddenly. It is used to relieve internal stress due to cooling or mechanical working, to produce soft steel suitable for machining, and to restore fine grain to steel which has been coarsened by overheating.

3. Tempering, which consists in reheating hardened steel to a certain temperature, much below that used in hardening or annealing, for the purpose of partially restoring its ductility and softness. The rate of cooling is unimportant. This process is used to produce a desired degree of toughness and hardness, and to raise the elastic limit to permit large deformations without permanent set, as in springs.

These three processes act through temperature changes merely to alter the molecular condition of the steel without varying the total carbon content. To these may be added a fourth closely allied process:

4. Case-Hardening, which consists of raising the carbon content of the surface of low carbon steel so that it can be hardened, annealed, or tempered like a high carbon steel.

Hardening.—The hardening of carbon steel is due to a change of internal structure which takes place

when it is heated properly to a definite temperature. This temperature varies with different steels. The process is applicable only to those having more than 0.20 per cent of carbon, and is usually confined to those in the neighborhood of 1.0 per cent. To understand the process it is necessary to glance at what happens to the internal structure of steel when it is heated and cooled.

In steel at normal temperatures the chief hardening component, carbon, occurs as a part of a constituent known as pearlite. If heated to a certain critical temperature the pearlite takes another form known as austenite, which gives steel its hardening property. If allowed to cool slowly from this temperature, the austenite changes back again to pearlite, and the steel becomes soft again. In Figure 30, the horizontal scale represents heat applied to a specimen of steel, and the vertical scale the rise in temperature. The heat, when first applied, all goes into raising the temperature of the piece until about 1350 degrees Fahrenheit is reached. At this point a change occurs. The temperature line not only ceases to rise, but actually falls as heat is added. This critical temperature is called the decalescence point, and varies with each kind of steel. The heat expended goes, not into raising the temperature of the piece, but into the work of producing the internal molecular change from pearlite to austenite. Since all the heat is going into molecular work there is even a fall in temperature, which is due to surface radiation. After the change is complete, any further heat added goes into raising the temperature until the final point is reached.

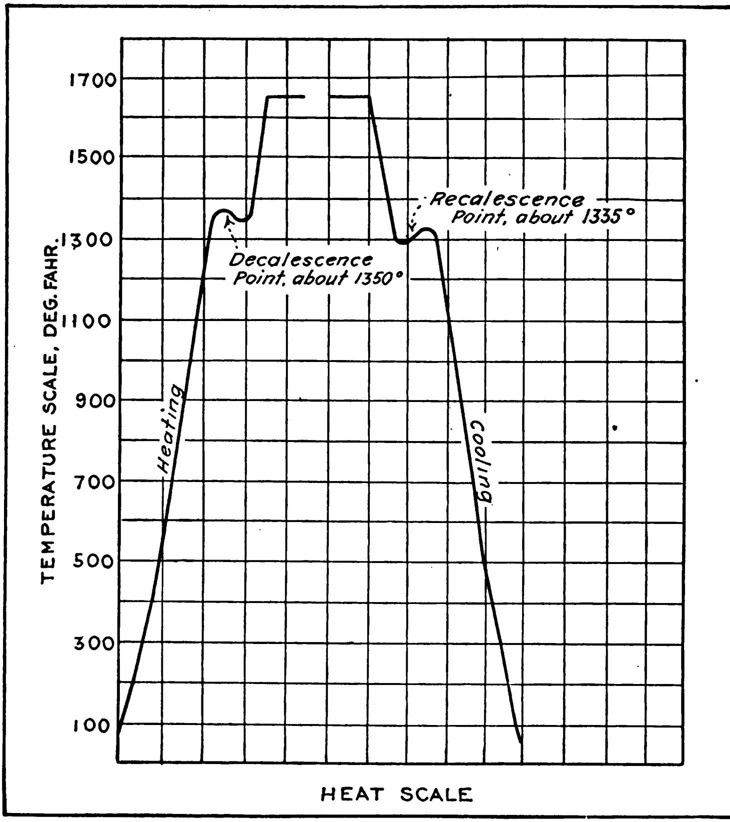


FIG. 30. HEAT-TEMPERATURE CURVE

If at this point the piece should be cooled slowly, heat is radiated away and the temperature falls until another point of inflection, called the recalescence point, is reached. In general, this will be somewhat lower than the decalescence point. Here the condition of the carbon is changed back to pearlite, and the energy previously absorbed is converted

back into heat. After this second change is complete, the cooling is resumed until the final temperature is reached. The change at the recalescence point requires a certain time. If, instead of being cooled slowly, the steel is quenched suddenly by being plunged into a cold bath, it passes through a complicated structural rearrangement, but does not return fully to pearlite, the soft form. The piece, when completely cooled, will be very hard and brittle, and the tensile strength and elastic limit will have been raised.

The hardness obtained will vary with the carbon content and the suddenness of the cooling. The correct hardening temperature is the lowest possible one above the decalescence point which will make sure that the steel has been completely changed into austenite. If heated considerably beyond this point the grain will be coarsened and the steel will be burned or oxidized. The danger of this is greater the higher the carbon content. The interesting fact that steel, when heated beyond this critical temperature, becomes non-magnetic may be made use of in determining the decalescence point. The composition of the quenching bath varies for different purposes, brine, oil and water being most used, and the degree of hardness obtained by quenching from the same temperature is greatest with brine, less with water, still less with oil. This is probably due to the rapidity with which the several liquids will absorb the heat. The above process of heating and quenching suddenly is used for hardening all carbon steels. Self-hardening or air-hardening steels, however, are hardened by slow cooling.

Heating.—Carbon steels should be heated slowly and evenly to the right temperature, kept from contact with air to avoid oxidation, and always quenched from a rising, not a falling, heat. Care should be used not to overheat any cutting edges and corners before the body of the material is brought up to the right heat. It is obvious that unevenness of temperature will cause a variation in hardness.

One of the common methods of heating is to use a bath of molten lead, potassium cyanide, or barium chloride. Care must be exercised in using these baths to have the piece absolutely dry before immersing it. The slightest moisture will cause the molten liquid to fly in all directions and burn the operator. The safest method is to heat the piece beforehand sufficiently to insure its being perfectly dry. At temperatures above 1200 degrees Fahrenheit lead gives off a poisonous vapor, and cyanide of potassium, as is well known, is an active poison. The furnaces used for heating these baths should be carefully guarded, and should be equipped with hoods to carry away the fumes. Powdered charcoal is often floated as a purifier on the top of the molten liquid.

Of the various baths, the lead bath is most used. It is especially adapted for heating small pieces that are hardened in quantities. The lead used should be pure, and free from sulphur. Various paints and pastes are used to prevent the lead from sticking to the work, or the piece may be heated and dipped into salt water just before immersion in the bath. Steel melting pots last much longer than those made of cast iron when the lead bath is used.

The potassium cyanide bath is much used for cutting tools, for dies, and in gun shops for color effects. The barium chloride bath, which has a high temperature, (about 2200 degrees Fahrenheit) is used to some extent with high-speed steels. The pieces are usually pre-heated in a gas furnace to a dull red in order to save time in the bath. For the lower temperatures required for carbon steels—about 1400 degrees—barium chloride and potassium chloride are mixed in the proportion of three to two. Temperatures below 1075 degrees are obtained by mixing equal parts of potassium nitrate and sodium nitrate. This mixture is used mainly as a tempering bath.

Modern heating furnaces are ordinarily oil or gas fired. Many types are on the market especially adapted for various sizes and kinds of products. The simplest type of gas furnace is a plain, circular pot of refractory material, as shown in Figure 31. Gas in general is a cleaner fuel than oil, but is more expensive. Where oxidation is objectionable, muffles or refractory retorts are used. Oil is the cheapest of all the fuels for large work. It is pumped under pressure to the furnaces from an underground tank, atomized in a suitable burner, and mixed with a proper proportion in air. Often a jet of steam is used which impinges on the hot brickwork of the furnace and is broken up into hydrogen and oxygen—both gases help in the combustion. Large heating furnaces are built up of brick and refractory linings, and are equipped with pyrometers to aid in controlling the temperatures. Coal and coke are inferior as fuels, as they are dirtier, the temperature control is more

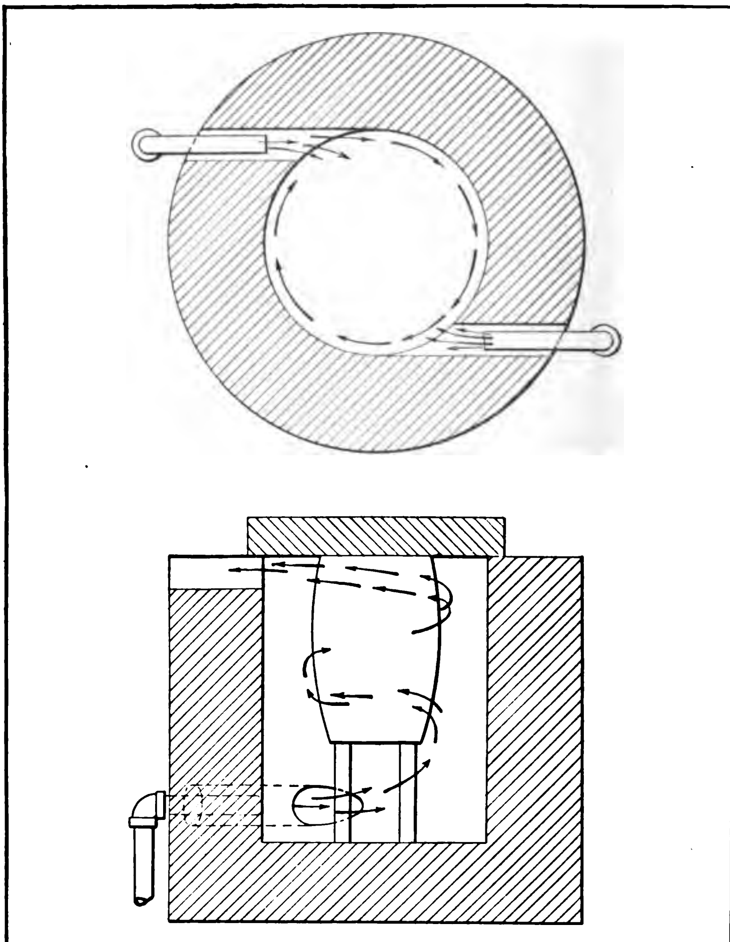


FIG. 31. SIMPLEST TYPE OF CRUCIBLE GAS-FIRED HEATING FURNACE

difficult, they require more labor in attendance, and the sulphur and other impurities are more or less absorbed by the steel being heated.

Quenching.—The hardening obtained by quenching will vary with the temperature, mass, and conductivity of the cooling medium. The degree of hardness obtained with various baths in 0.90- to 1.0-point carbon steel ranges in the following order: mercury, carbonate of lime, brine, pure water, soap water, milk, oils, tallow, and wax. These different materials are used for different purposes. Oil, having a lower viscosity and heat-carrying capacity, cools the steel comparatively slowly. It is therefore used when the piece is to be tough rather than very hard. Water, being higher in heat-carrying capacity, cools the steel more quickly, making it harder and brittle. Brine makes it still harder. For excessively hard work, quicksilver is sometimes used. Delicate and complicated pieces cannot be cooled in brine without danger of warping and cracking.

The temperature of the bath is important, as water, for instance, at 60 degrees will give a greater hardness than water at 150 degrees. A large body of liquid is better than a small one, because the heat given out by the steel will raise the temperature of a small bath where it will have no appreciable effect on a large one; and the capacity to carry away heat is increased if the liquid is in circulation. Clear water is generally used for ordinary carbon steel, sperm or lard oil for springs, and linseed oil for cutters and other small tools. Certain portions of an article may be hardened more than the rest of it by

having cool jets of the quenching liquid impinge on the surface at these points. This method is used for hardening the face of forging dies, by immersing them face downward into the quenching bath and causing a jet to play into the impressions. In cooling, these impressions will become harder than the rest of the die.

Skill and care are required in successful quenching. The pieces should not be thrown in carelessly, because unsymmetrical cooling will cause warping and cracks and, even if these do not develop, will produce severe internal strains, which are all the more dangerous because they may not show on the outside. Even with the best of care warping cannot be wholly obviated, and for this reason very accurate machined pieces must be ground after heat treatment.

There are a number of rules which apply generally. The piece should be stirred in the bath to break up the coating of vapor which tends to gather on its surface and retard the rapidity of cooling. Stirring also serves to bring the piece into cooler portions of the bath. Long, thin pieces should be quenched in the direction of the principal axis of symmetry, to avoid warping. A gear wheel should be hardened perpendicularly to its plane, and a shaft vertically. Hollow pieces should have the ends plugged, since otherwise they cannot be quenched vertically without the formation of steam inside. When pieces have thick and thin sections the thicker portions should be immersed first.

Self-Hardening Steels.—These steels are obtained by the addition of chromium and other elements, as

already mentioned. The proper form of treatment varies with the composition, and the directions given by the makers should be followed. Usually they are heated to a red heat and cooled in an air blast, or dipped in oil. It is not necessary to draw the temper. Great care is required in heating them for forging, since the forging heat has a very narrow range of temperature and they may be very easily spoiled. Some grades of self-hardening steel may be annealed by heating to a bright heat in the centre of a good forge fire and allowing the fire to die out, the fire and the steel cooling off together. Steel so annealed may be hardened again by heating to the hardening heat and cooling in oil.

Taylor-White Steel.—This type of steel should be heated slowly to red heat and then, as quickly as possible, to a temperature just short of the melting point, when it begins to show signs of softening. It should then be cooled suddenly in oil to a low red heat. From then on the cooling may be either fast or slow, down to the temperature of the air. Taylor-White, or high-speed steel, is no harder than hardened carbon steel. It has, however, the remarkable quality of "red hardness;" that is, the steel remains hard even at a red heat, which corresponds to something over 1000 degrees Fahrenheit, while ordinary carbon steels begin to soften at about 390 degrees and lose all of their hardness when heated to about 700 degrees. The larger part of the work done by a cutting tool goes into heating the object cut, the chip and the point of the tool. In continuous, heavy cutting at high speed, that portion of the heat entering the tool

will raise the temperature high enough to draw the temper of carbon steel. When this occurs the tool begins to soften, the edge is lost, and the cutting qualities are gone. In high-speed steel there is a leeway of more than 600 degrees before this action takes place, and consequently much higher cutting speeds and heavier cuts are possible than with carbon steels.

Annealing.—In making complex steel forgings it is impossible to heat all parts alike. Some parts therefore cool from a higher temperature than others. A uniform fine grain may be given them by annealing. Steel castings are also annealed to relieve internal strains due to the unequal cooling after pouring, and to refine the grain. The steel is heated to a little above its critical temperature, as if for hardening, but instead of being cooled suddenly, it is allowed to cool from this temperature very slowly. When this is done, the fine-grained austenite structure has time to readjust itself in passing the recalescence point, and thereby acquires its natural pearlite structure. When it is completely cooled it will be soft and tough.

The principal difference between the annealing and the hardening process, therefore, is the substitution of slow cooling for sudden quenching. Steel, to be annealed, should be packed in boxes in powdered charcoal or lime, sealed in order to prevent oxidation, and heated slowly. Very low carbon steel should be heated to about 1625 degrees Fahrenheit, and high carbon steel to 1475 degrees. The heat should be held there long enough to insure an even temperature

throughout the piece that is being annealed. As with hardening, the piece should not be heated much beyond the critical temperature. If this is done the grain is coarsened and the steel may be decarbonized. Slow cooling is the essential feature of the annealing process.

Brass and copper are also annealed. When these metals have been drawn or rolled to more than a certain percentage of reduction, they become hard and brittle and will split on further working. The soft structure may be restored by heating them to a dull red heat and allowing the pieces to cool. Unlike steel, these metals may be cooled suddenly as well as slowly.

Tempering.—Tempering is a secondary process, coming after hardening, and the reheating is always to a temperature much less than the critical or hardening temperature. The main purpose of this process is to reduce the brittleness and increase the toughness, but unfortunately it always undoes to some extent the work of hardening. If the piece is reheated to only a low temperature, most of the hardness and brittleness will remain. The higher the temperature to which it is heated, the more of these qualities will be taken out until, if it is heated to above the critical temperature, they will entirely disappear and the tempering process will have become annealing. Cutting tools should always be left as hard as possible, and yet tough enough for the work intended.

The Color Scale.—When hardened steel is heated, the color changes with the rising temperature from a pale yellow through a darker yellow into brown,

brown-purple, purple, and finally to a dark blue. This color scale has long been used as a gauge for temperatures in tempering. Its use requires great skill and uniform conditions of lighting, and so on, if uniform results are to be obtained, and for accurate work a pyrometer should be used. The color scale, with the corresponding temperatures and the class of tools for which they are used, is given below.

COLOR AND TEMPERATURE SCALE FOR TOOL HARDENING*

Color	Degrees		Class of Tools
	Fahr.	Cent.	
Very pale yellow	430	221	Punches, Scraping Tools, Drawing Dies
Light yellow	440	227	Milling Cutters, Reamers
Pale straw yellow	450	232	Twist Drills
Straw yellow	460	238	Counterbores
Deep straw yellow	470	243	Edging Cutters
Dark yellow	480	249	Pipe Cutters
Yellow brown	490	254	Knurling Tools, Pen Knives
Brown yellow	500	260	Threading Dies and Taps
Spotted brown	510	266	Cold Chisels
Brown purple	520	271	Small Taps
Light purple	530	277	Dies for threading to a shoulder
Full purple	540	282	Springs
Dark purple	550	288	Molding Cutters
Full blue	560	293	Wood Saws
Dark blue	570	299	

Edged tools, such as chisels, are tempered by heating the cutting end to a cherry red and then quenching the part to be hardened. When the tool is removed from the quenching bath, the heat remaining in the unquenched part of the tool will raise the tem-

* This table is compiled from Machinery's Mechanical Library, Vol. VIII, pp. 70 and 76, and Rose's "Modern Machine Shop Practice."

perature of the cutting end to the desired color when the entire tool is quenched. The modern method of tempering in quantity is to heat the pieces in a bath of molten lead, heated oil, or other liquid, the temperature of which may be kept within very close limits. Beds of heated sand and salt are also used. The use of baths or sand beds is preferable to open heating because there is a closer control of the temperature which determines the degree to which the tempering is carried. High-speed steel does not require tempering. It should be cooled in some thin oil, such as lard or paraffine. If paraffine is used the piece should be kept under the surface until cooled to the temperature of the bath; otherwise the oil will ignite.

Carbonizing.—Carbonizing is a very valuable process for a good many classes of articles in which the contradictory qualities of toughness and hardness are both wanted. Low-carbon steel is tough, but cannot be hardened. High-carbon steel can be hardened, but becomes brittle in the process. Case-hardening is simply the partial carrying out of the old cementation process of making steel, in which bars of wrought iron were heated a long time in the presence of carbonaceous material, and the carbon given off was absorbed by the iron until its carbon content was raised to the point desired and it became steel.

In case-hardening the process is carried on long enough to drive the carbon in to the depth desired. A low-carbon steel, properly packed in carbonaceous material and maintained at a temperature of 1650 degrees Fahrenheit for about two hours, will be changed

to 80 point carbon steel to a depth of about 1/64 inch; heating it for four hours will case-harden it to 1/32 inch, and the carbon will be 1.0. If it is heated for six hours, the case-hardening will be 1/16 inch deep and the carbon content 1.15. In case-hardening, the material is packed in cast-iron boxes or pots with the carbonizing material, such as charcoal, charred leather scraps, or burnt bone. It is then covered and sealed. A number of case-hardening compounds are on the market and may be used instead of the materials mentioned, as some of them have become too valuable for general case-hardening work.

If the piece is quenched after being case-hardened, the surface, having been transformed into high-carbon steel, will become hardened to the depth of the case-hardening, and the soft low carbon interior, which cannot be hardened, will remain tough. The article will therefore have the double qualities desired. The "Harveyizing" of armor plate is case-hardening applied on a large scale. Quenching from the same heat is practiced when only color effects and a hard surface are desired. For a better quality of temper the piece is cooled slowly, and hardened after a subsequent heating, since the hardening temperature is not so high as the case-hardening temperature and a second heating gives better results.

CHAPTER XI

THE TOOL ROOM—FIXTURES AND GAUGES

The Tool Room a Modern Development.—As there will be no frequent references in the chapters dealing with machine tools to the tool room and to tool-room methods, it is well to consider briefly the functions of the tool room and the part they play in machine-shop methods. The tool room is a modern development and an embodiment of the principle of the subdivision of labor. The typical figure in the old-time machine shop, which built its products before manufacturing methods became general, was "the general all-round mechanic." He was a man of skill and experience. He ground his own tools to suit himself, and sometimes even forged them. With the possible help from time to time of an overdriven foreman, he decided how the work was to be done, set the work upon the lathe or planer, and measured it to determine the setting of the tools, generally using his own scales and small tools in the process. Much of his time went into work that could be done by a less skilled man, and his measurements, however skillful, were subject to more or less variation.

Relation of Tool Room to Shop.—The general mechanic has largely disappeared from the machine rooms of the modern shop that turns out interchange-

able products. His work has been split up into that of the skilled tool-maker and that of the handy man, or machine tender, who does little more than set the work into a fixture and tend the machine. The tool-maker now plans the operations, makes the small-tool equipment to carry them out, and maintains the machines in proper condition. The tool department also sharpens the tools and takes care of them, issuing them to the workmen as needed. The tool room carries on such important work that it has well been called "the heart of the shop." It is here that the quality of the output of a plant is set, and maintained. A good tool room usually implies a good shop, and a good shop cannot exist if there is a poor tool room.

The quality of the work done throughout the plant will run down and the cost of production go up under the following conditions:

a. If the producing machines throughout the factory are not properly equipped with the necessary fixtures and cutting tools.
b. If the tool equipment is not maintained in good condition.
c. If the gauges used to check the quality of the product are not properly designed, well made, and kept in repair.
d. If the tools, fixtures, and gauges are not at all times ready for use.
e. If they cannot be found promptly when wanted.
f. If the producing machines themselves are not maintained in good repair. Good tool equipment on a worn-out machine will do bad work.

Functions of the Tool Room.—The foregoing considerations determine the functions of the tool room, which are three in number.

The first function is to build and maintain fixtures,

gauges, special machines used for manufacture, and such small tools as are not purchased from outside. This cares for items a, b, and c, and, as pointed out in a previous chapter, involves close touch with both the drafting room and the shop. This is particularly important in the manufacture of interchangeable products. Some shops have a tool-room committee, analogous to the design committee described in Chapter II. Such a committee is composed of the tool-room foreman, the principal machine-room foreman, and the drafting-room man who is in charge of tool design. No new design of such an article as a gun is complete until a list of operations giving the number and order of operations has been settled upon, including all the working points, as they are called, which are the points or surfaces used for locating the work during the various cutting operations.

Another list giving the sequence of the gauging operations and their relation to the manufacturing operations should be settled upon at the same time. These are necessary before any work can be intelligently started on the fixtures, special tools, and gauges which are to be built. Before these lists are determined upon, all those modifications of the design of the product which are desirable for economy in manufacture, must have been made. Few things will demoralize a tool room more completely than continued tinkering with the design of new output after work has been started on the tools.

The second function of the tool room is to sharpen and grind all tools and maintain them in proper working condition. There is a right and best way to grind

each tool. If the decision of this question is left to the whim or fancy of each machine hand, few tools will be ground properly and there will be no standards of tool practice in the shop. Furthermore, special tool-grinders have been developed which not only turn out correctly ground work, but enable this work to be done by labor much less skilled than the general mechanic.

The third function of the tool room is to store and to charge out the small-tool equipment and supplies to the workmen as needed. This is done by a tool storeroom, which may or may not be a part of the main tool-room organization.

The Tool Storeroom.—The functions of the tool storeroom are:

a. To protect tools against loss, theft, deterioration, and confusion.

b. To provide a place for every tool, which place shall be reserved for that tool and identified with it.

c. To provide means for locating where any tool is when it is not in the storeroom. This is done through some form of check system or its equivalent.

d. To show what tools any man has at any given time.

e. To maintain records covering breakage, wear, and so on, which will furnish a basis for determination of tool costs.

The storage facilities should be as simple as possible, should conform to a well thought out plan, and should be readily intelligible, economical of space, and capable of expansion.

In general, the tool-building for the entire plant may be centralized in one room or department for convenience in administration, but the tool-grinding

and tool-storage may sometimes be divided to advantage and carried on in small storerooms about the plant, one in each department—the controlling consideration would be, what arrangement, under the given conditions, will entail the fewest steps and least loss of time?

Machine Equipment.—The machine equipment of the tool room for a moderate-sized plant will consist of one or more of the following machines:

- High-class lathes, 8 to 24 inches, seldom for work over 6 or 8 feet long.
- Universal milling machines, with index head, etc.
- Horizontal boring mills.
- Die-sinking machines.
- Planers, moderate size.
- Shapers.
- Drill presses.
- Radial drills.
- Precision grinders, for surface and circular work.
- Rough grinders.
- Power hack saw.
- Full equipment of standard gauges adapted to the work in hand, such as plug and ring, screw-thread and pipe gauges, gauges for standard tapers, surface plates, squares, etc.

These machines will be used in the general tool room. To these may be added drill and milling cutter grinders, lathe and planer tool-grinders, and so on, which may be either in the main tool room, or the branch tool rooms if there are any throughout the plant.*

* For the design of fixtures, gauges, and special tools, see "Tools and Patterns," by A. A. Dowd, Vol. 4, Factory Management Course.

Policies.—Certain policies are desirable in tool-room practice. Day wages prevail because of the variety and accuracy of the work. In making tools precision of workmanship is more desirable than great economy of production. The tool-room foreman should be the best man obtainable. The best is not too good, for there are few men in the whole plant who have greater influence on the quality of the work and the cost of production. If the tool room is of fairly large size, the principles of standardization can always be profitably applied on such details as cutters, shanks, bushings, tapers, and so on. Often the work may be subdivided into skilled and less skilled functions, and the workmen may be chosen accordingly. New tools and fixtures should be estimated on, the estimates covering the anticipated saving; and these estimates should be checked with the cost of the fixtures and the actual saving in output realized. This offers one of the few checks possible on the work of the tool room.

Fixtures and Jigs.—A fixture may be defined as a device for locating and clamping work in proper position for a machining operation. A jig is a device for guiding a cutting tool; usually it is combined with a fixture. These terms are used loosely and in most shops interchangeably, but properly speaking a fixture relies upon the machine to locate and guide a cutting tool with reference to the work. While a jig often locates and clamps the work, it combines with this means for guiding the cutting tool during its operation. A fixture is usually clamped firmly to the table of the machine; a jig is usually free to move

and to find its own position, as in the case of a drilling jig, which centers itself on the point of the drill. I shall not attempt here to go into the details of jig and fixture design, but shall consider merely general principles, partly economic and partly mechanical.

Economic Principles.—1. The jigs and fixtures should be suited to the work. This is not so obvious as it it seems, for there are many ways of doing most operations and many instruments that can be used, and the selection of the best ways and means is often a matter of skill and experience.

2. They should not be idle most of the time. Sometimes a fixture is built which will perform an operation in one-half or one-third of the time required without it, but the total money value represented by the saving may not be large enough to justify the expense. A saving of 5 per cent on the cost of a much-used operation may justify a greater tool expense than a saving of 90 per cent on another operation which goes through the shop only occasionally.

3. Fixtures should show an adequate return on the investment through the saving in cost of operation, or should materially improve the quality of the output. Well-designed fixtures usually do both. When the cost of the fixtures is balanced against the saving in operation cost, the wear and maintenance of the fixtures, which is usually considerable, must be taken into account and charged against it.

4. Fixtures should be arranged, whenever possible, to perform simultaneous operations. This not only saves cost of handling, but usually increases the accuracy of the output.

Mechanical Principles.—1. Fixtures should be firm enough to equal the stability of the machine and the cutting tool, and should be heavy enough to preclude all chattering.

2. The clamping devices should be rapid in action and positive in locating the work. The clamping is usually done by screws and nuts, toggle joints, or cams. In general, it is desirable, whatever the clamping device, to have a quick motion set the jaws up on the work, and then a slow movement with increased power to produce the clamping effect.

3. All vises, and like equipment used for holding work should have one fixed jaw, and the rotation of the cutter and the thrust of the feed should be against this jaw.

4. There should be adherence to the definite working points laid out in the list of operations. If possible the working point should come against the fixed jaw.

5. Parts which locate the work or clamp against it, and in the case of jigs the legs also which bear on the drill-press table, should be tool-steel hardened, or machinery steel case-hardened.

6. There should be clearance in the corners for dirt and for burrs left from any previous operation, as well as ample room for the chips to get away.

7. All wing nuts, handles, levers, and so on, should be made large enough to operate with a moderate pressure. If this is done, the fixture will work faster, be more accurate, and last longer than if these parts were skimped. Wherever the workmen is hammering these down with a mallet after setting them

up by hand, he is losing time and is in serious danger of springing the work, or the fixture, or both.

8. In the case of multiple fixtures, avoid stacking the pieces against one another. Every piece should be set against a solid stop.

9. In the designing of fixtures for formed milling operations, the piece should be so positioned that the various sections of the milling cutter will be as nearly the same diameter as possible.

10. If possible, the locating points should be so arranged that the piece cannot be placed in the fixture in a wrong position.

11. In the case of drilling jigs it is desirable to have four legs bearing on the drill table. If the table is out of true, or if one of the legs is resting upon a chip, the rocking of the jig will show it. A three-legged jig, like a three-legged stool, will sit firmly on an irregular surface, and consequently the operator will not detect an unevenness that will be shown up by a four-legged one.

The following additional points are brought out in "A Treatise on Milling and Milling Machines" by the Cincinnati Milling Machine Company:

> The clamp should be immediately above the supporting point. Disregard of this leads to springing of the work, or lifting of the work due to support point being transformed into a fulcrum.
>
> Three fixed supporting points should be the maximum for any rough surfaces.
>
> Supporting points for finished surfaces should be as small in area as is consistent with the pressure to be exerted by the clamps.

All supporting points should be set as far apart as the nature of the work will allow.

All side clamps should be arranged to press downward.

The fixed supporting points should always circumscribe the center of gravity of the work.

All supporting points over and above the original three should be sensitive in their adjustment.

All clamps and adjusting support should be operated from the front of the fixture.

All clamps and support points that are operated or locked by wrench should have the same size head.

Support points should be set so . . . as to minimize the amount of cleaning required.

Support points should have provision for easy removing and replacing in the event of breakage.

Fixed support points should have provision for adjustments to take care of variations in castings from time to time.

Clamps should be arranged so that they can be easily withdrawn from the work. This is to avoid lengthy unscrewing of the nut in order to give ample clearance between clamp and work.

Springs should be used to hold clamp up against clamping nut. This is to avoid the falling down of the clamp and the consequent loss of time attendant on holding it up while inserting the work beneath.

Supporting points and clamps to be accessible to the operator's hand and eye.

Adequate provision for taking up end thrust so that this will not be dependent upon friction between work and clamp.

All of the above axioms are applicable to almost every type of fixture.

Gauging.—Extensive and well-planned gauging is necessary in any machine shop where interchangeable work is being done. There is a constant tendency toward degredation of quality from the wear of tools, machines, and fixtures, and of the gauges

themselves. No work is ever done exactly to size. Precision workmanship simply means that the deviations are known to be very minute.

Three terms are used in connection with these deviations. The greatest and least dimensions above and below the nominal size which will be permitted to pass inspection are called "limits." These limits have been determined carefully as the extremes between which the piece is sure of being usable for the purpose designed. If these are exceeded the work must be rejected. The difference between the two limits is called "tolerance." Deviation from the nominal size within the limits is unintentional, but permissible. "Allowance" is an intentional difference in size of two parts which are to go together. If the joint is to be a drive fit, the hole is purposely made a certain amount smaller than the other member. If a running fit is desired, it is purposely made a certain amount larger. It is evident that limits may be set for the two dimensions called for by the allowance.

Types of Gauges.—For the ordinary gauging of surfaces and angles, it is customary to use surface plates, squares, and protractors. For very accurate work precision methods are used, which will not be taken up here.

For linear distances the simplest form of gauge is the graduated scale, which has the advantage of being available for any length within its limit and of not wearing out in use. It is the least accurate form of gauge, but a skilled man with a caliper will take off dimensions from it to within .002-.003 inch. The

graduated scale constitutes what is known as a line measure, where the eyesight is relied on in determining the size, and because of its convenience, it will always have a place where great precision is not required. Figure 32 shows several of the more commonly used gauges. End measures, as they are called, comprise bars of standard length, plug and ring gauges, and "snap" gauges. When these are used, the work is gauged by the sense of touch and not sight. They are far more accurate than the ordinary line gauges, but in general they are good for only one size and are subject to wear. Differences of a few ten-thousandths of an inch may be easily detected.

The vernier and micrometer types of calipers combine the advantages of both line and end measure systems, and have at the same time the accuracy of touch of an end measure and the wide range of sizes within their limits characteristic of the linear scale. The vernier and micrometer calipers were both introduced by the Brown & Sharpe Manufacturing Company, the vernier in 1851 and the micrometer in 1867. The influence of these two types of gauges, especially that of the latter, upon the standards of accuracy in commercial work has been very great, for they placed in the hands of the workman convenient and practical tools capable of measuring differences previously unrecognized in practical shop work. It is a well-defined principle that the limit of precision in production is what you can measure.

The linear scale, the vernier, and the micrometer are used mainly in the tool room. For general production work, plug and ring gauges, and snap-

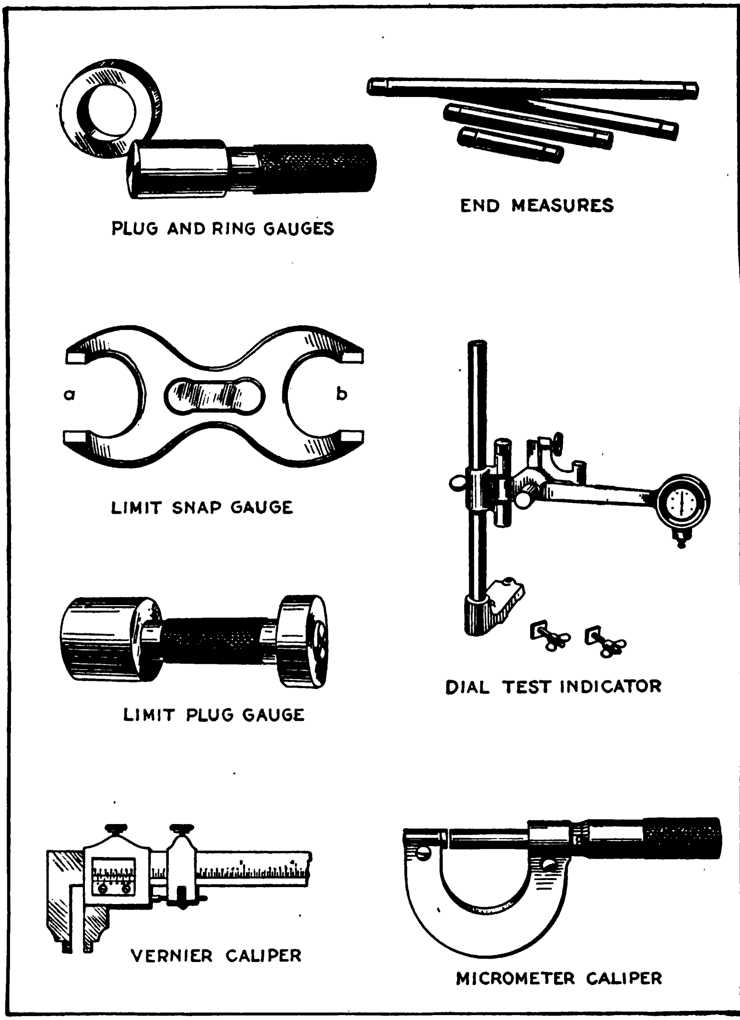


FIG. 32. TYPES OF GAUGES

gauges, Figure 32, are more used. Any of these may combine two sizes and become a limit gauge. These relieve the workman in the shop of the necessity of exercising judgment in determining sizes and machine fits. The working gauge supplied him embodies two dimensions representing the limits allowed, the difference between them being the tolerance. All the workman has to do is to make sure that the work will pass "A," and will not pass "B." The limit gauges shown are of the very simplest form. For special work, they are varied to suit the special case.

Gauges of another class—such as difference gauges, dial gauges, and indicators—are used by tool makers, not so much to determine absolute distances as to ascertain differences from some standard. For instance, the diameter of a shaft would be measured by a micrometer or snap gauge, but its variation in alignment would be measured by an indicator or dial gauge in thousandths of an inch without reference to the size.

The correctness of special profiles or contours given to any piece of work is determined by a "receiver" gauge, such as that shown in Figure 33. The piece is located by a pin, A, which fits into the hole, B. It must slide on to the pin, A, and fit accurately into the receiving space, C, which has the contour desired. The receiver gauge shown is also provided with a snap gauge, D, on the edge, which is used to gauge the thickness, E, of the piece. The one shown is very simple in character. When the surfaces are irregular, and intricate in their relationship the gauge may become a delicate and complicated affair.

Another class of gauges is used for locating the po-

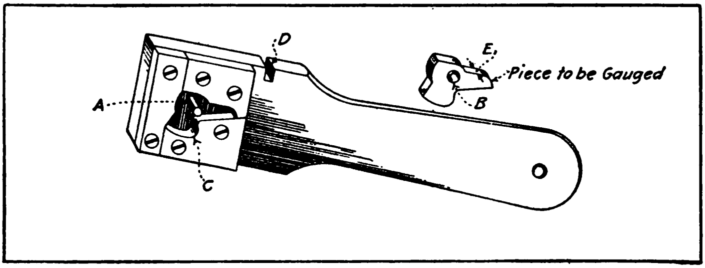


FIG. 33. CONTOUR GAUGE

sition of pins, holes, and surfaces. Profile or receiver gauges may include this feature, as in the gauge shown in Figure 33, which locates the hole, B, with reference to the contours of the piece. The pin, A, is in effect a plug gauge for the hole, B. The more intricate gauges may be used for all three forms of gauging—for size, contours, and location.

General Considerations.—In shops where accurate work is done in great quantities there will be three sets of similar gauges: working gauges, used by the workman during production; inspector's gauges, used by the shop inspectors, and master gauges, used to check the other gauges.

The working and inspector's gauges are used continually and are therefore subject to wear. The master gauges remain in the tool room and are used for reference only; they therefore retain their size a long time.

Gauging is done at various stages during the progress of the work:

a. First piece inspection—gauging by the tool-setter or in-

spector, to insure the correct setting of the cutting tools and fixtures before proceeding with the work.

b. Working inspection—gauging by the workman during the progress of the run, to discover wear of cutting tools, etc., or changes in setting.

c. Operation inspection—all the pieces put through may be gauged by an inspector before proceeding with the next operation. This is done to detect bad work in the early stages of manufacture, and thereby to save doing further work on a piece already spoiled.

d. Piece inspection—by the inspectors, of the finished part before it is sent to the assembling room.

e. Selective inspection—This is often practiced when the pieces are simple and made in very great quantities, such as hardened balls for ball bearings. To gauge each one would add greatly to the cost of production. Only one out of a certain lot or number is gauged; if this passes inspection, the rest are assumed to be correct; if not, others are gauged and if a certain number are found incorrect the whole lot is rejected.

f. Unit-assembling inspection—usually done in the assembling room, to make sure that parts of certain definite units, as, for instance, a typewriter carriage or a lathe head, are in proper relation to one another. This may involve very refined types of position gauges.

g. Performance inspection—by the inspectors, of the performance of the machine as a whole.

I have taken up the work of the tool room in the foregoing consideration only in a most general way, for the purpose of making clearer what follows. For detailed consideration of tool-room practice and the design of fixtures, gauges, and special tools, the reader is referred to Volume 4, Factory Management Course, on "Tools and Patterns," by Albert A. Dowd.

CHAPTER XII

CUTTING TOOLS

Material.—Since the purpose of all the machine tools is to drive some form of cutting tool, before taking up the machines I shall take up the various forms of cutting tools used. Cutting tools are made from tool steel or from some form of abrasive. The latter material forms the basis of grinding wheels; while their action is that of pure cutting, they constitute a distinct type of tool and will be taken up in another chapter.

Carbon Steel.—Formerly, tool steels for cutting purposes were composed of iron, carbon, and minor elements which were either neutral or which acted as impurities. These steels, known as carbon steels, have been in use for many generations. The carbon content, which varies from 0.80 to 1.50 per cent, gives the steel the hardening and tempering qualities already considered. Good carbon steel properly heat-treated is as hard as any of the later kinds of steel, and in fact will take a keener cutting edge. Its limitation, as compared with high-speed steel, comes from the fact that it begins to lose its hardness when heated above 400 degrees Fahrenheit and consequently cannot be used for such heavy cuts or high-cutting speeds. For finishing work and for light, ac-

curate cuts, however, carbon steel is as good as any other.

Mushet, or Self-Hardening Steel.—This kind of steel was developed between 1860 and 1870 by Robert Mushet, an Englishman, who introduced about 5.5 per cent of tungsten and 1.6 per cent of manganese into the steel, which caused it to be almost as hard when cooled slowly in the air from a forging heat as carbon steel when quenched in water; hence the name air-hardening, or self-hardening, steel. This steel would cut faster and stand more abuse than any steel then known.

High-Speed Steels.—About 1900, Frederick W. Taylor and Maunsell White patented a steel that had the quality of "red hardness," so called because it would remain hard and retain a cutting edge even after the edge was red hot. A cutting tool made of this steel could be operated on cuts so heavy and fast as not only to turn a steel chip dark blue, but even to make it red hot. In the later steels described by Mr. Taylor in his "On the Art of Cutting Metals," the tungsten is given at 18.9 per cent, chromium 5.47 per cent, carbon 0.67 per cent, and manganese 0.11 per cent. He gives the following cutting speeds for these various steels when cutting machinery steel:

Jessop carbon steel,	16	feet per minute
Mushet steel,	26	"
Original Taylor-White steel,	58	"
Taylor-White steel, 1906,	99	"

Many brands of high-speed steel are now on the market. Compared with carbon steel it is very expen-

sive, and various forms of tool-holders have been devised to economize in its use. Its advantage over carbon steel is most marked in the making of heavy, rough cuts, work in which the purpose is to remove as much material as possible in a short time.

Mr. Taylor's paper, "On the Art of Cutting Metals," read before the American Society of Mechanical Engineers in 1906, is one of the greatest contributions ever made to machine-shop practice. In this discussion he points out that the three fundamental questions which must be answered every day, in every machine shop, in connection with metal-cutting machines such as the lathe, the planer, the drill press, the milling machine, and their like, are:

1. What tool shall I use?
2. What cutting speed shall I use?
3. What feed shall I use?

He then describes experiments which covered 26 years, employed the best energies of a number of experts, and had a profound effect not only upon cutting steels but upon the whole design of machine tools. He shows how many variables were involved in answering the three questions above, and the principles of successful experimentation in working out a problem of that nature. He reviews the history of the investigation with the successive improvements developed, and lays down standard shapes for cutting tools, and methods and formulas for determining cutting speeds. He also gives a full description of the composition and the method of heat-treating high-speed tool steel. While the paper deals mainly with heavy

roughing operations, it is a mine of general information and should be read by every one interested in the art of cutting metals.

A wide variety of cutting tools is used for the various types of operations throughout the shop. The principal types will be considered briefly.

The Lathe-Planer.—This type of tool has been used for a hundred years or more and is the typical cutting tool used on lathes, boring mills, planers, shapers, and so on. It has a single cutting edge, shaped to suit the particular type of cut; a few of the standard forms of cutting edge are shown in Figure 34. The principal ones are the "round nose," A, and diamond point tool, B, the most common of the lathe tools. These remove chips easily, and are used for both roughing and finishing cuts. Certain angles have generally recognized names. The angle, a, is called the top rake; b, the side rake; c, the clearance angle, and d, the angle between the cutting edges. C and D are right- and left-hand side tools; E, is a parting, or cutting-off, tool; F, is a bull-nose tool; G, a finishing tool. There are some minor differences between the tools used on lathes and on planers respectively, but the general type is much the same in both cases. Lathe tools should be set so that the cutting edge is slightly above the center. If they are set so that it is below the center, the material is scraped off instead of cut off and the cutting edge is soon lost. If the cutting edge is too far above the center, the pressure comes on the front of the tool, and not on the cutting edge. On many planer tools the end is goose-necked, as shown in H, Figure

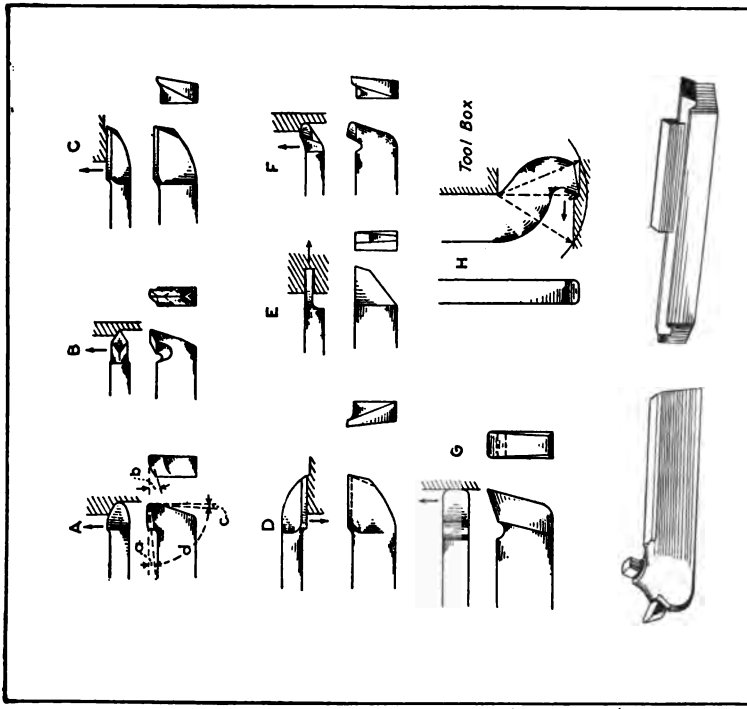


FIG. 34. TYPES OF LATHE AND PLANER TOOLS

34. If the cutting edge is forward of the supporting surface on the tool head, it will tend to dig into the material when taking a heavy cut or upon striking a hard spot in the material. If the cutting edge is even with, or back of, the supporting face, this tendency is done away with.

The advantages of the lathe-planer type of tool are that it is easily sharpened, and can be used for a wide variety of operations. Its disadvantage lies

in the fact that since the work is concentrated on a single small cutting edge, the wear is rapid and the tool must be frequently re-ground. With carbon steels the shank and nose of the tool are usually a single forging; when the cutting edge has worn down beyond a certain point, the tool is re-dressed by the blacksmith and used over again. This process may be repeated until the shank has become too short to be used in the tool-holder. High-speed steels are too expensive to be used in this way. Figure 34 shows two forms of tool-holders in which the shank, or body, is a machinery-steel forging carrying at its end a clamping device for holding a small bar of high-speed steel which can be moved up toward the cutting point with each successive grinding and nearly all of which can be used.

What the best form of tool will be, depends on the kind and hardness of metal to be cut, the character of the cut—whether roughing or finishing—and the manner of presenting the tool to the work. Since a tool cuts by wedging action, the sharper the cutting angle the less power it takes to drive it. The cutting angle, d, should therefore be as small as is consistent with strength. In general the angle may be more acute for the soft metals than for the harder ones such as chilled cast iron or tool steel.

The surface of most metals, especially that of castings, is harder than the interior, and is liable to contain some sand or scale. For this reason a first, or roughing, cut should be deep enough to go beneath this hard surface; otherwise the tool will be quickly dulled. For roughing cuts, metal can be removed

most rapidly by taking heavy cuts at low speed; for finishing cuts, it is better to use a fine feed and faster speed. The principal limitations of feed and speed lie within the tool itself, in the strength of the tool, the wear of the cutting edge, and the heating of the tool with a consequent loss of hardness. In addition to these limitations there may be others, from lack of stability in the work, which may be too weak to stand up against a heavy cut and spring away from the tool; or the lack of stability may lie in the machine tool itself. One of the most far-reaching effects of Dr. Taylor's work was a general re-design of machine tools to furnish the power and stiffness required for the new high-speed steel tools. If springing is bad in the work and the machine, it is, of course, equally bad in the tool itself, and the supporting point of the tool should be as near the cutting edge as possible. Cutting speeds vary so much that only a general idea of them can be given here. For good grades of carbon steel, such as Jessop's, the approximate cutting speeds are as follows:

For cast iron......................	30— 40	feet per minute
For wrought iron..................	25— 30	"
For steel..........................	15— 40	"
For brass.........................	60—100	"

The cutting speed is of course affected by the amount of feed—a higher cutting speed is possible with a light feed than with a heavy one.

For high-speed steel the approximate speeds are as follows:*

* "Modern Shop Practice," Vol. I, pp. 93-94.

Soft cast iron	50— 60	feet per minute
Hard cast iron	20— 40	"
Hard cast steel	30— 40	"
Soft machine-steel	60— 90	"
Hard machine-steel	20— 30	"
Wrought iron	35— 45	"
Tool steel annealed	50— 80	"
Tool steel not annealed	15— 20	"
Soft brass	110—130	"
Hard brass	90—110	"
Bronze	60— 80	"
Gun metal	40— 60	"

A general idea of the feeds possible can be gained from the following table.

Roughing cuts on cast iron	4— 5	per inch
Roughing cuts on machine steel	5— 8	"
Sizing cuts on cast iron	12—16	"
Sizing cuts on machinery steel	16—20	"
Finishing cuts on soft cast iron with a narrow-point tool	15—25	"
Finishing cuts on machinery steel with a narrow-point tool	20—40	"
Finishing cuts on cast iron with wide-faced tool	1— 4	"
Finishing cuts on machinery steel with wide-faced tool	4— 8	"
Finishing cuts for brass, according to kind of cut and shape of tool	10—40	"

The above speeds and feeds are for tools of the lathe-planer type.

Multiple Tool-Holders.—Tool-holders may be arranged to carry two or more tools of the lathe-planer type, arranged one behind the other with reference

to the direction of feed. The first one takes a roughing cut, the second one takes up the cut where the first one leaves off, and so on to the last one, which acts as a finishing tool. This is done for heavy work, and is found more frequently on heavy lathes and planers than elsewhere.

Single-Edged Forming Tools.—When the finished surface is to have some curve or other definite shape, this shape may be incorporated in the cutting edge of the tool. Such tools are known as forming tools. They may be either flat as shown at A, Figure 35, or formed bars, as at B, or circular as at C. In forms A and B the required shape is given to the front edge, and the grinding is done on the top. In form C the cutter is in the form of a surface of revolution. Part of the tool is cut away, leaving a cutting edge

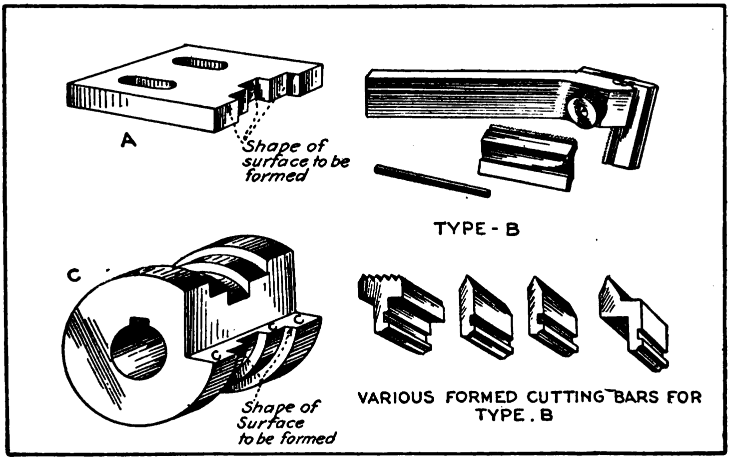


FIG. 35. TYPES OF SINGLE-EDGED FORMING TOOLS

as shown. When the edge becomes dull the flat face, c, is ground away as much as may be necessary. This process may be carried on until the whole circumference of the tool has been used.

Milling Cutters.—Figures 36 and 37 show various forms of milling cutters—used on milling machines—profilers, die-sinkers, and so on. In these a number of cutting edges are arranged around the circumference of a rotating tool, which is cylindrical, or some surface of revolution. The cutting speed comes from the revolution of the cutter, and the feed is usually given by moving the work against the cutter, although this is not necessarily so. Although they are generally considered as more modern, milling cutters are as old as the lathe type of tool. A milling cutter made in 1780 by Jacques Vaucanson, a French mechanic, is now in the possession of The Brown & Sharpe Manufacturing Company. This cutter, like most of the early milling cutters, has very fine teeth. Modern experiments, however, have shown that milling cutters with few teeth are much more efficient.

The milling cutter has a wide and increasing use. The wear is not concentrated at one place, as in a lathe tool, and the milling cutter will therefore hold its shape longer. The cutting edge of the lathe tool is in the work during the entire time of the cut; with the milling cutter, any single cutting edge is in the work only a small proportion of its revolution. Consequently with a good stream lubrication it has time to cool, which means that the cutting speed can be higher. While the cutting done by any given edge is intermittent, the cutting is continuous so far as

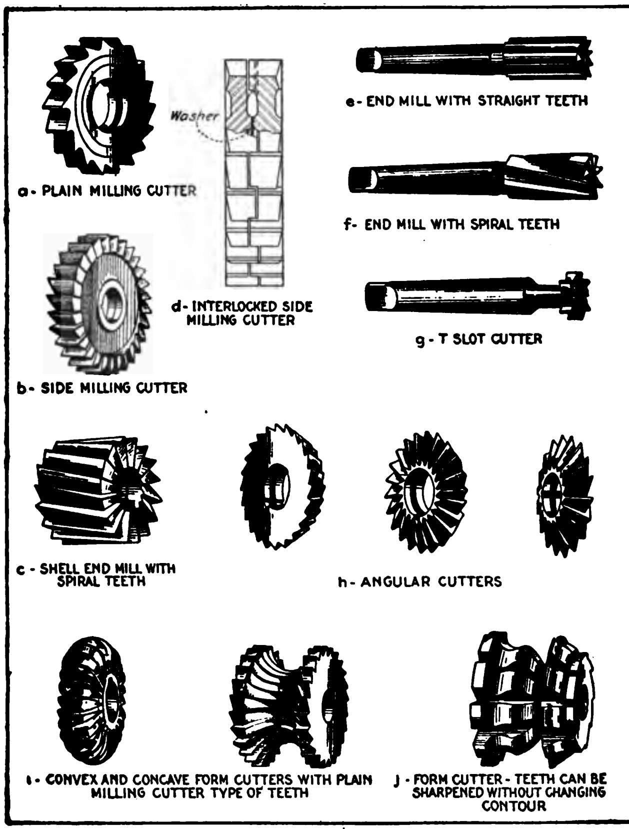


FIG. 36. STANDARD TYPES OF MILLING CUTTERS

FIG. 37. MILLING CUTTERS WITH OPPOSED SPIRALS

the work is concerned. There is therefore a saving in time over a planer which has the idle return stroke.

Milling cutters are made in an infinite variety of forms. The plain milling cutter, a, Figure 36, has teeth on the circumference only, and they are parallel to the axis. When the teeth are parallel, as in this type, the entire cutting edge strikes the work at once, giving a tendency to produce chatter, which increases with the width of the cutter. When milling cutters are long, the teeth are arranged spirally, to avoid end-thrust. Two cutters, one with a right-hand spiral and one with a left-hand spiral, may be placed side by side, as shown in Figure 37. The side-thrusts then will neutralize each other. Frequently the teeth are nicked, as shown, to break up the chips. These nicks do not appear on the work, since they are staggered in each successive tooth, so that a high spot left by any nick is cleared away by the tooth following. Cutters made in this manner can be run at coarser feeds than those with plain teeth.

The side milling cutter, b, Figure 36, is similar to the plain one, except for the addition of teeth on one or both sides. When it is necessary to maintain accurately the distance between the two faces, two such cutters are placed side by side with their teeth "interlocked"—that is, with the alternate teeth on each mill reaching over into the zone of the other cutter (see d, Figure 36). This is done to avoid a fin or burr on the work, which might be left by the crack between the two cutters. The width between the side faces is maintained by packing thin washers between the cutters each time the teeth are ground.

A face milling cutter has teeth on the periphery and on one face. It is carried on the end of the machine spindle, the teeth on the flat face being in full contact with the work, while only a small length of the teeth on the periphery acts on the piece. The shell end mill is similar to the face mill, but is used for light operations. It may be solid, with a taper shank, or separate, as shown at "c." End mills with right-hand teeth usually have a left-hand spiral and vice versa. This tends to force the shank of the mill solidly into the spindle of the machine. The T-slot cutter, g, has teeth on its periphery and alternating teeth on the side. It is used for milling T-slots in fixtures and machine tables. Angular cutters, h, have their teeth cut at some oblique angle. They are employed for finishing dove-tails and on a wide variety of work calling for surfaces machined to some required angle.

Formed cutters (i and j) are an important class. There are two kinds in general use. In the first, the teeth are of the same character as those of plain milling cutters and are sharpened by grinding on the top. As ordinarily done, this changes the contour of the teeth and of the outline produced by them, which is a serious objection when it is necessary to maintain the original form. Special machines have recently been developed for regrinding this type of cutter, and at the same time preserving the original contour. The other style of cutter has teeth that are "relieved," but the contour is retained so that they may be sharpened repeatedly without changing the original form so long as the teeth are ground radially on their faces.

With this style of cutter interchangeable work of a regular outline may be produced more cheaply than by any other method, and this type is widely used for cutting gear teeth, the contour of the cutter being the same shape as the space between the gear teeth.

The fly cutter is the simplest form of milling cutter. A tool similar to the lathe type which may have any desired form of cutting edge is inserted in a holder and acts in the same way as one of the cutting edges in an ordinary mill. It has, of course, only one cutting edge, but it can be made at little expense and is used for short operations on special work.

When milling cutters are large, the cost of making them entirely of tool steel would be very high. This cost may be reduced by making the body of the mill of machine steel and inserting cutters of tool steel. In Figure 38, "A" and "B" show cutters of this type, and "C" shows one of the methods of inserting the teeth. The upper screw pulls down a wedge which forces the cutter against a shoulder integral with the body of the mill. Both the hole in the wedge and the hole in the body of the mill are threaded. The holding-down screw engages the threads in the body of the mill, but does not engage with those in the wedge. Its action is therefore to draw the wedge downward. When it is necessary to remove the wedge, the holding-down screw is taken out and a second screw, shown below, is inserted. The action of this screw, as clearly shown by the figure, is such as to withdraw the wedge.

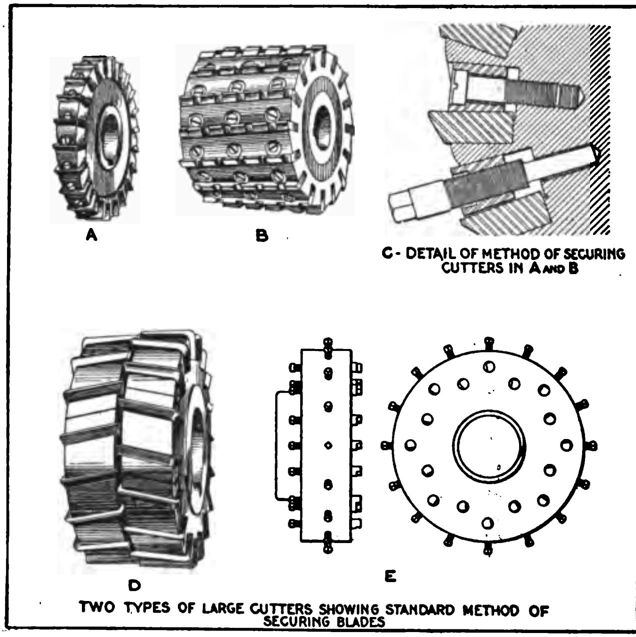


FIG. 38. TYPES OF INSERTED-TOOTH MILLING CUTTERS

Gang Mills.—These receive their name from the fact that two or more cutters are placed together on the same arbor and are used at the same time. (See Figure 39.) "Sometimes plain milling cutters are so combined in order to cover a wider space; and again, formed cutters may be used either with or without plain or side milling cutters. The use of formed cutters and plain milling cutters together should be avoided on account of the difficulty of maintaining the relative diameters in sharpening. . . . Gang milling reduces the cost of production and insures

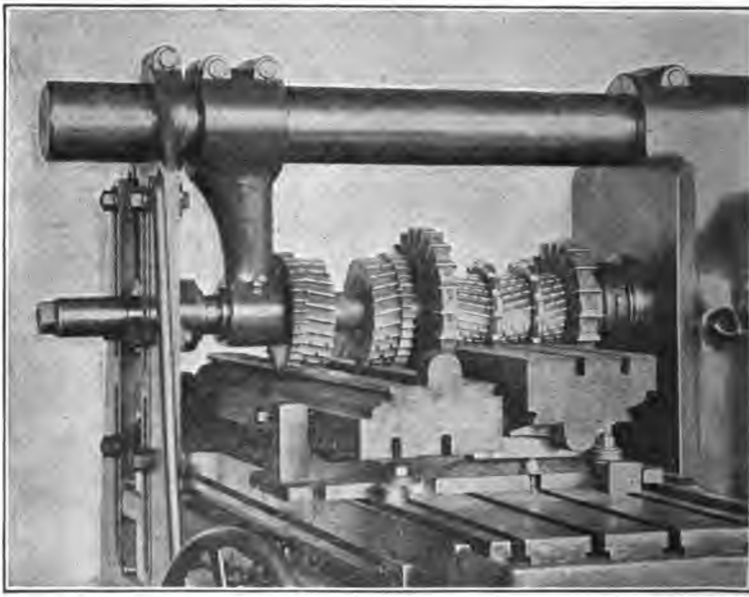


FIG. 39. HEAVY GANG MILLING CUTTER

accuracy of work, as several operations can be performed simultaneously and at one setting."*

In milling of this kind the cutters of the largest diameter, which of course have the heaviest work to do, should if possible be nearest the spindle, and it is often desirable to have some of the cutters right-hand and some left-hand spirals in order to equalize the end-thrust. Sometimes, when the cutters vary considerably in diameter, the inequality of the peripheral speeds may be cared for by having the large cutters made of high-speed steel and the smaller ones of carbon steel.

* "Treatise on Milling Machines," Brown & Sharpe Mfg. Co.

Speeds and Feeds.—The speeds and feeds in milling operations are dependent on the power and rigidity of the different machines, kind of material, width and depth of cut, and quality of finish required. No definite rules are established. Delicate work requiring accurate finish calls for light cuts and fine feed. In general, the speed should be as fast as the cutter will stand, and the feed as coarse as is consistent with good work. The following surface speeds, advocated by Brown & Sharpe in their treatise on "Milling Machines," will give some idea of prevailing practice:

CARBON STEEL CUTTERS	SPEED IN FEET PER MINUTE
Brass	80 to 100
Cast Iron	40 to 60
Machinery Steel	30 to 40
Annealed Tool Steel	20 to 30

HIGH-SPEED STEEL CUTTERS	SPEED IN FEET PER MINUTE
Brass	150 to 200
Cast Iron	80 to 100
Machinery Steel	80 to 100
Annealed Tool Steel	60 to 80

Drills.—Drills are used for originating holes in solid stock. A drill rotates, and is provided with cutting edges located at its point. It is distinguished, therefore, from a reamer, which has cutting edges on the sides. Drills are of two general classes. The flat drill, shown at "A," Figure 40, is the oldest type, but is comparatively little used today.

The prevailing type of drill is the twist drill, shown

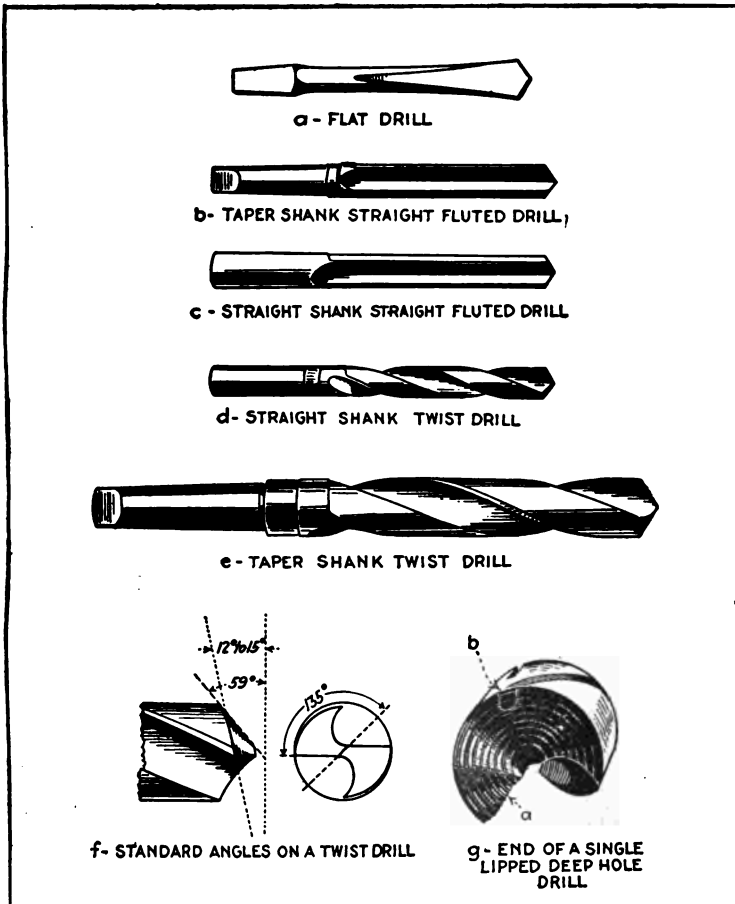


FIG. 40. TYPES OF DRILLS

at "D" and "E," Figure 40. This usually has two spiral flutes, which are sharpened on the end, and are ground down as the tool wears. Twist drills are made in all sizes, for the smallest hole up to about four inches in diameter, although they are not common much above two inches diameter. They may have straight shanks, or tapered shanks made to one of the well-known standards prevailing, such as the Morse taper, which is 5/8 inch to the foot. This type of drill was developed about 1860, and has marked a very important advance in mechanical history. There are many refinements in the design and manufacture of these drills which cannot be taken up here. The point of the drill, F, Figure 40, is ground off at an angle of 59 degrees with the axis. The ends are not truly conical but are slightly spiral to give relief to the cutting edge, the angle of clearance being 12 to 15 degrees. It is very essential that the two lips of the drill should be absolutely symmetrical, that is, the cutting edges at equal angles and of equal length; otherwise the pressure will be heavier on one side than on the other, and the drill will run out and bore a hole larger in diameter than the drill itself.

The speeds of drills must be varied to suit the material. It is well to consult the tables recommended by the manufacturers of twist drills for special cases. The following recommendations are made by the Cleveland Twist Drill Company:

If no table is at hand and the operator is in doubt as to the correct speed for a twist drill, it is a safe rule to start carbon steel drills with a peripheral speed of 30 feet per

minute for soft tool steel and machinery steel; 35 feet for cast iron, and 60 feet for brass; and a feed of from .004 to .007 inch per revolution for drills one-half inch and smaller, and from .005 to .015 inch per revolution for drills larger than one-half inch. At these speeds and feeds a good cutting compound is recommended. In case of high-speed drills the above feeds should remain unchanged, but the speeds should be increased to from 2 to 2½ times.

The cutting compound referred to is mainly for the purpose of cooling the tool. The following compounds are recommended in the order named:

For hard, refractory steel—turpentine, kerosene, or soda water.

For soft steel and wrought iron—lard oil or soda water.

For malleable iron—soda water.

For brass—a flood of paraffine oil, if any.

For aluminum and soft alloys—kerosene or soda water.

Cast iron should be worked dry or with a jet of compressed air.

Special forms of drills are used for many purposes. For drilling soft metal, such as brass, especially when the drill passes entirely through the piece, straight fluted drills of the type shown at C, Figure 40, are used. For deep-hole drilling, such as rifle barrels in hard stock, a special form shown at G, Figure 40, which has a single cutting edge, a, and a passage, b, for the cutting lubricant, which is fed under pressure, has been developed.

In general, the drill is not a very accurate tool. There is a heavy pressure on the conical point, which tends to press the tool off to one side if the conditions at the point are not exactly right. The surprise is not so much that they are inaccurate as that

they do their work as well as they do. When very accurate sizes are required, holes are first drilled and are then reamed.

Reamers.—The ordinary reamer is a tool with long, straight cutting edges running parallel with its axis. (See Figure 41.) The general form of the cutting portion resembles that of a small milling cutter, but the tool is used in the manner of a drill rather than like a milling cutter. When a reamer is used in a hole that goes entirely through the piece, it is desirable to pass the reamer entirely through the hole, because the front end of the reamer, having the greatest work to do, is subjected to the greatest wear. Oil is used when reaming wrought iron or steel. Small reamers are solid; large ones are made with inserted cutters to save tool steel. This also provides means for setting out the blades to compensate for wear and regrinding—many forms of expanding reamers of this character are on the market. Reamers are used for taper holes as well as for straight ones, the angle of the cutting edges conforming to the taper desired. As reamers are used only for sizing work, it is desirable to remove as much of the material in the drilling operation as possible, since to do so means decreased wear on the reamer, with increased accuracy of work.

Taps.—Many holes that are drilled have to be threaded afterward. For small holes this is done with taps—three forms of taps most commonly used are shown in Figure 42. It is customary to have the shank smaller than the root diameter of the thread. This allows the tap to fall through the hole when

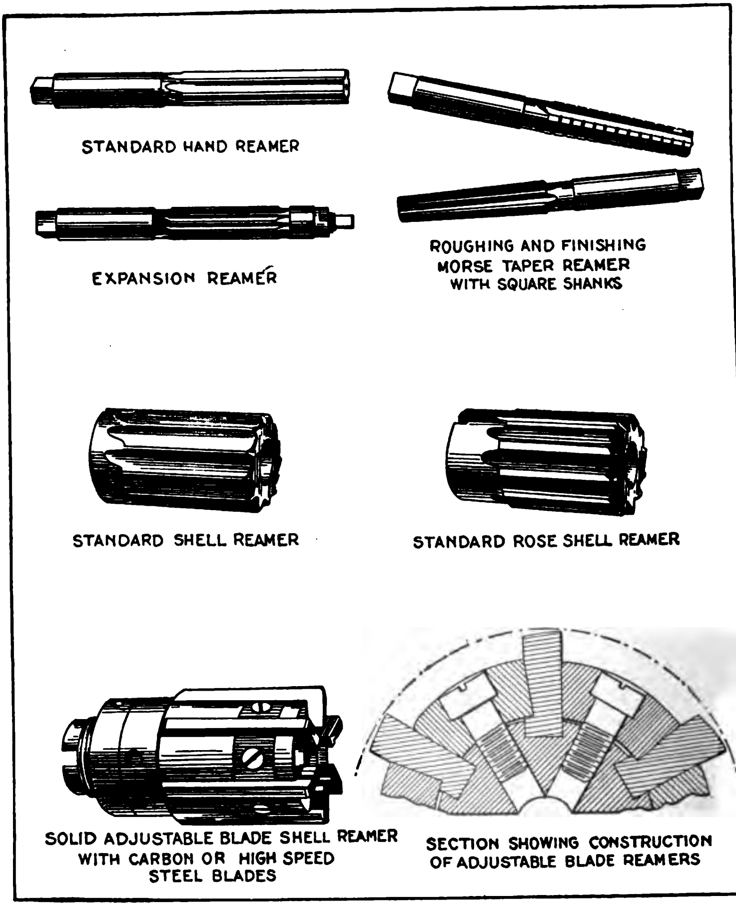


FIG. 41. TYPES OF REAMERS

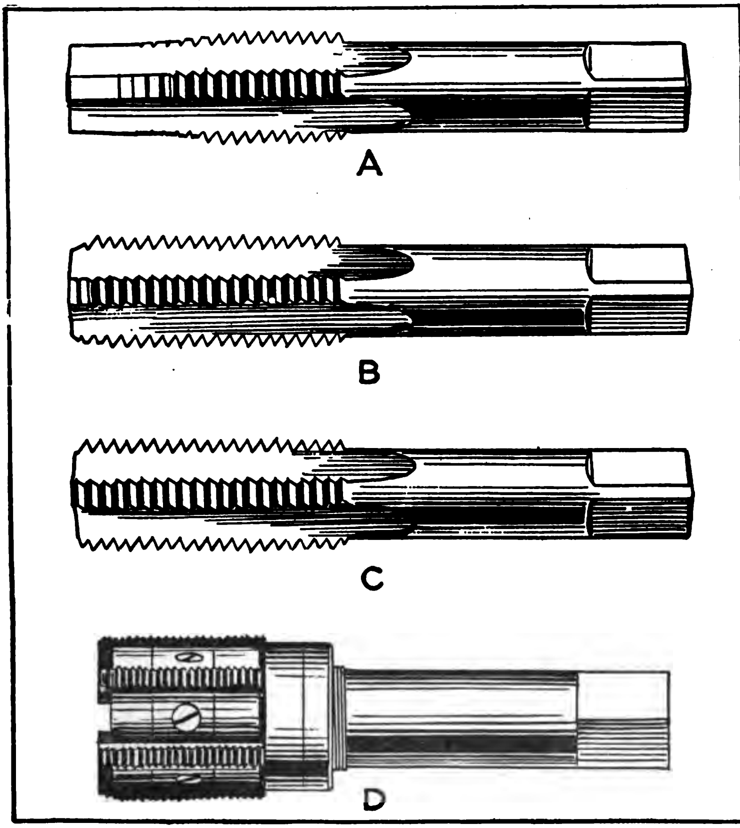


FIG. 42. TAPS

the threading operation is completed, and renders it unnecessary to reverse the tap to back it out, a feature which is especially valuable in hand operations. The square on the end fits loosely in the socket on the driving spindle, so that the tap is free to fall. Most of the screw threads used in this country conform to the "Sellers" or "United States" standard,

but there are other well-established forms that are used for special purposes. The desirability of uniformity in screw threads is so great that the standard should not be departed from except for very good reasons. The detailed consideration of the various standard forms of threads, and their uses, will be given in the chapter on Thread Cutting.

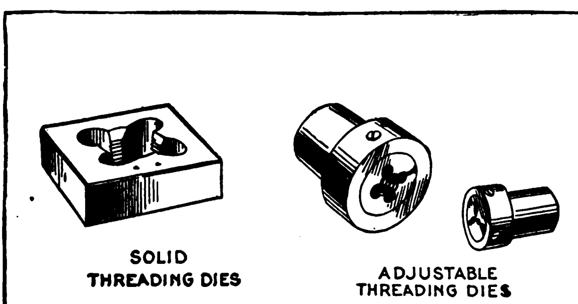
There is a wide variety of taps for special purposes. The first one shown, A, Figure 42, is known as the tapered tap. It will be noted that the whole of the thread is cut away on the front end, the amount gradually lessening until full threads are left in the upper part of the tap. This distributes the work of cutting along the length of the tap, and consequently relieves the wear on the threads. The final threads have little to do except to bring the work to exact size. This type of tap is used in holes that go clear through the work. The second, or plug, tap, B, is used for threading holes that do not go through, but where a few imperfect threads at the bottom of the hole are not objectionable. The bottoming tap, C, is used when it is necessary to cut the threads quite to the bottom of the whole. This form is not used except when absolutely necessary. As will be seen, the plug tap is a compromise between A and C.

Taps are also made with long shanks when threads are required at the bottom of a long hole. As the size of the tap increases, a point is reached where inserted tooth cutters become profitable, as in the case of milling cutters and reamers. This also allows for adjustability in connection with regrind-

ing. Taps, like other cutting tools, must have relief back of the cutting edge, and in most of the solid taps now used, when they are reground on the face there is a slight change in size. When the taps are large enough, this may be compensated for by splitting the tap and spreading the sections apart with a threaded taper plug which acts along the axis of the tap, as shown in D, Figure 42.

Dies.—Taps are used for cutting internal threads; external threads are cut in dies. Figure 43 shows the simplest form of solid threading die. Dies as well as taps must have a relief back of the cutting edge, as they also will lose their size on regrinding. This may be compensated for by slitting the die and springing it together with an adjusting screw in the holder. Another method is to split the die into two portions and make these adjustable in the die-holder toward each other. For large work and for accurate threading various forms of self-opening dies are used, which will be described later under Screw-Threading.

Punches.—Punches are used for originating holes



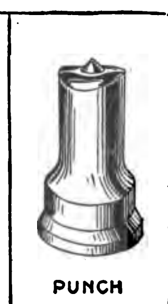


FIG. 43. THREADING DIES FIG. 44 PUNCH

in thin stock when accuracy is not required. They are usually round, but there is no reason why an odd-shaped hole may not be punched as well. The simplest form of punch is a short, cylindrical tool with a flat end which goes through a corresponding ring known as the die. The material is placed between the two, and the punch forces a plug, or wad, the size of its own diameter through the hole in the die. The die is always fixed to the bed of the machine, and the punch is carried on a movable power-driven head. The work of punching with a punch that has a flat end is very severe, since all of the circumference begins to cut at once. A punch with a curved edge of the type shown in Figure 44, relieves the suddenness of this shock. In this type the conical point in the middle enters the plate first, and holds it securely. The lower portion of the curved edge enters the work first, and the highest portion is last. This distributes the work of cutting through a vertical zone represented by the difference in height of the lowest and highest portions of the edge. A punch does not have to cut its way entirely through the plate, as the plug, or wad, is sheared completely from the surrounding material after the punch has gone part way through, and from then on the punch has merely to push the plug out. The percentage of the work actually performed to the apparent work of cutting the entire thickness of plate is lowest for thick plates, varying from about 25 per cent on a one-inch plate, and 37 per cent for a half-inch plate, to about 75 per cent for a plate 1/16 inch thick. For very thin plates, it approaches 100 per cent. In large machines, a num-

ber of punches may be operated in "gangs." Punching is the cheapest and most rapid way of producing holes in sheet stock. It is, however, an inaccurate and rough process, and when accurate work is required the holes should be drilled.

Shears.—Shears, as their name implies, are used for cutting bars or thin sheets. In the case of bars, the cutting edge may be either V-shaped or formed to suit the material. For cutting plates, straight-edged shearing blades are used; these have the cutting edge set at an angle to distribute the work of cutting and to relieve the machine from the shock that would result if the entire edge entered the work at once.

Saws.—These are also used for cutting up rough stock. The familiar wood-saw has its counterpart, used for cutting metal. The hack saw is usually a small, light band of tool steel, about ¾ inch wide, with a hole in each end. This is mounted in the frame of an automatic machine which gives the blade a proper motion. Special machines are arranged to carry two or more saws. Circular saws also are used for metal—they generally consist of a soft steel disk with inserted tool-steel cutting teeth. These, like the hack saws, do their work by pure cutting action.

An especially interesting type of saw consists of a thin disk of soft steel which runs at very great peripheral speed, as high as 15,000 feet per minute; the edge has no teeth whatever. This saw is brought into contact with the piece to be cut, and a heavy stream of water is directed at the point of contact. The friction of work to be cut is concentrated at the point

of contact; on the saw it is distributed around the entire circumference, and the cooling stream is sufficient to preclude heating. The disk therefore literally melts its way through the work with a rapidity incredible to those who have not seen it work. This type of saw may be used to cut hardened tool steel. In this case the temper will be drawn for a slight distance possibly 1/64 or 1/32 inch back from the surface. This may be ground off on an emery wheel down to the hard metal and the piece, if it is a cutting tool such as a threading die, will be again ready for use.

There are many special forms of cutting tools which do not fall under any of the classes described. Some of these, such as broaches, hobs and forming tools for stampings, will be taken up in connection with the machine tools with which they are used.

Cutting Lubricants.—A list of the cutting lubricants suggested by one of the well-known firms was given in connection with twist drills. In most of the machining operations some form of lubricant is used, the conspicuous exceptions being the cutting of cast iron and brass, which is done dry. In general, lard oil is an excellent lubricant when turning or threading steel or wrought iron, and it is largely used on automatic screw machines, especially on small work. For high cutting speeds, soda water is more satisfactory, as oil is more sluggish and does not reach the cutting point with sufficient rapidity. Many cutting compounds are on the market which consist usually of a mixture of carbonate of soda and water, with lard oil or soft soap to thicken it, and which

act as a lubricant. The different kinds of lubricants for the various types of cuts on the various metals are so many that they cannot be taken up here. Frederick W. Taylor was the first to point out the great saving in stream lubrication for a cutting tool. One of the principal limitations to the cutting speed is the rise in temperature of the tool, with the consequent drawing of the temper and loss of cutting edge. He discovered that a heavy stream of water—not the little dribble previously used, but a heavy stream poured directly on the chip at the point where it was being removed by the tool—would permit an increase in cutting speed amounting in some cases to 30 or 40 per cent. The stream is used, not for lubrication, but for the purpose of carrying away the heat generated at the point of the tool. This practice has become very general for heavy roughing cuts of the kind described by Dr. Taylor.

CHAPTER XIII

LATHES

Development of the Lathe.—The lathe is the oldest of the machine tools. In its rudimentary form—as, for instance, the potter's wheel—it comes down from the earliest dawn of civilization. In the old whip lathe the work was mounted on two centers. A cord was run from a long wooden spring, secured to the ceiling, down to the work, around it for one or two turns, and then on down to a foot treadle on the floor. By the working of the foot treadle the piece to be cut was oscillated backward and forward, and a hand tool, resting on a guide in front of the work, was used to do the cutting. The cut was taken with every alternate movement as the work rotated forward. Later, the continuous revolution was substituted for oscillating motion, but the driving cord was still carried around the piece itself. In the next step in the development, the work was mounted on centers as before, but was connected by suitable means to a live spindle which had a permanent pulley driven by the belt. With all of these types only hand cutting tools were used. It is rather surprising, as we look back, to see what good turning was done in this way at such an early period of mechanical development.

Henry Maudslay and Modern Tools.—Modern tools really had their beginning with the application of the "slide rest" principle to turning lathes by Henry Maudslay, a principle which has been extended to nearly every form of machine tool. It was first developed by Maudslay between 1790 and 1800 in the shop of Joseph Bramah, in London. Instead of being manipulated by hand, the cutting tool was clamped solidly in a tool post carried on a slide rest movable along accurately finished guides on the bed of the machine. For many years the slide rest was known in English as "Maudslay's Go-Cart."

In its first and simplest form the motion was controlled by hand-operated screws. In a short time, provison was made for connecting the operating screws by gearing to the driving spindle, giving the tool a power feed. This invention enormously increased the accuracy of the machine as well as the size of the cuts which could be taken. The old hand tools had to be skillfully used, for occasionally they "dug in" and lifted the workman over the lathe.

The lead screw, for which, also, Maudslay is responsible, followed within a very few years, and was a natural development from the slide rest. In its first form, Figure 45, a lead screw with the same number of threads per inch as it was desired to cut, was attached to a slide rest and driven at the same speed as the work. This caused the cutting tool in the slide rest to move forward over the work and generate the screw thread required. It, of course, necessitated a separate lead screw for every pitch to be cut. Within a year or so Maudslay developed the idea

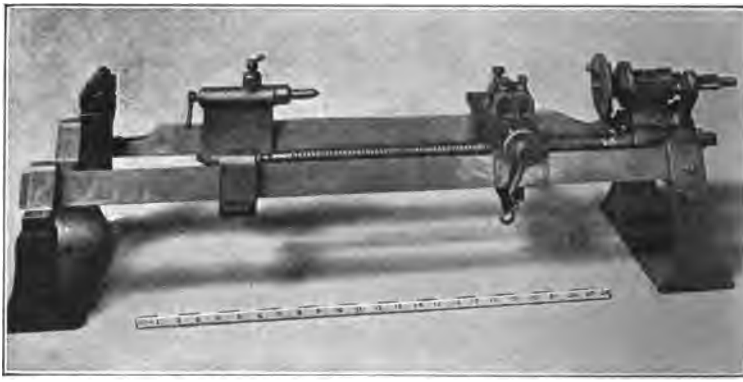


FIG. 45. MAUDSLAY'S FIRST SCREW-CUTTING LATHE, ABOUT 1797

of a single lead screw, much more accurately formed, which could be made to cut any pitch of thread by changing its turning velocity, relatively to the work, through a gear reduction. The various gears used to change the speed of the lead screw are still known as "change gears."

These essential features of the screw-cutting lathe, although varied in proportions and greatly improved in workmanship, remain unchanged in principle to this day. Maudslay lived until 1830; shortly before his death he built a lathe capable of turning work 12 feet in diameter and boring steam cylinders up to ten feet in diameter, which shows the remarkable development in this machine during the lifetime of one man. So important were Maudslay's contributions that he may well be termed the father of modern machine tools. The back gears used to increase the power of the drive were invented by Richard Roberts about 1817. From 1830 onward there was little de-

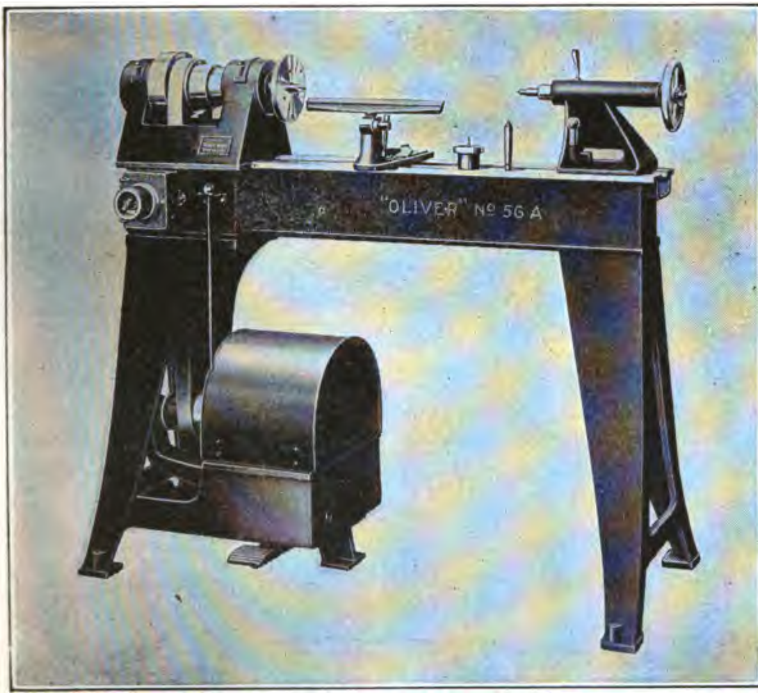


FIG. 46. SPEED LATHE
Oliver Machinery Co.

velopment in the essential design of the turning lathe until, about 25 years later, the turret lathe was developed, and later still the automatic turret lathe. Both of these are American in their origin.

The Speed Lathe.—The simplest form of lathe used today is the speed lathe, Figure 46, which consists of a bed having guides or ways on its top, and at one end—invariably the left-hand end as the workmen faces the machine—a headstock, or casting, containing two bearings. In these bearings is the live spin-

dle, and between the bearings is a pulley, called the cone pulley from its step-like form, which is used to drive the work. At the right-hand end is the tail-stock, which contains the dead center, one of the conical points on which the work turns. The front of the driving spindle contains the other center, which is known as the live center, because it rotates with the live spindle. It is highly important that this should run true, or it will cause the work to revolve in an eccentric path.

On the end of the live spindle just back of the center is a flat plate, called the face plate, which, for metal turning, is notched. The work is mounted on these two centers, and a projection, usually the horn of a lathe dog secured to the work, engages with this notch. The turning force is transmitted through the live spindle, the notch in the face plate and the dog, to the work, which rotates freely about the axis of the two centers. An adjustable slide carries a light, straight rest, which is set parallel with the work, and a hand tool resting on this support close to the piece turned, is manipulated by the operator to make the desired cuts. This form of lathe is so simple that its construction will be understood from the illustration without further explanation. Speed lathes are little use now for metal turning; they are mainly confined to pattern shops and wood-working plants, where they will always have a place, as the work of cutting is not heavy and a hand tool may be used freely and safely.

The Engine Lathe.—The rather archaic name of "engine" lathe still clings to the standard type of

metal-cutting lathe which is power driven and equipped with a slide rest and screw-cutting attachment. The principal elements of the engine lathe, Figure 47, are the bed, headstock, spindle, back gears, tail stock, slide rest or carriage, apron, a lead screw, change gears, and feed rod. Auxiliary attachments that go with the lathe are the chuck, steady rest and follower, dogs, taper attachment, and boring bar. The lathe bed is the main frame that carries the working parts. For small and moderate-sized lathes this is carried on legs at, or near, each end. Frequently one of these legs, usually the left-hand one, is expanded into a box or chest.

It is desirable to have the center line at a level convenient for operation. Consequently, as the size of lathes increases, the bed becomes lower, the legs shorter, and finally, in the largest sizes, the legs disappear altogether and the bed rests directly on the foundation. (See Figure 53.) Generally the cross-section of the bed consists of two parallel girders, approximately of an I-section, braced across at frequent intervals. On the tops of these girders are the ways, which in America are inverted V-shaped guides. The European tool-makers prefer flat, square slides, but the universal practice in the United States is to make the ways of inverted V-section. There are two sets of these ways, one on each side; the outer pair carry the slide rest, and the inner pair the head- and tail-stocks. In some lathes a single V is used for one side of the slide rest; the other side resting on a flat surface. In small and medium sizes, it is quite common to have an oil pan for catching oil and chips,

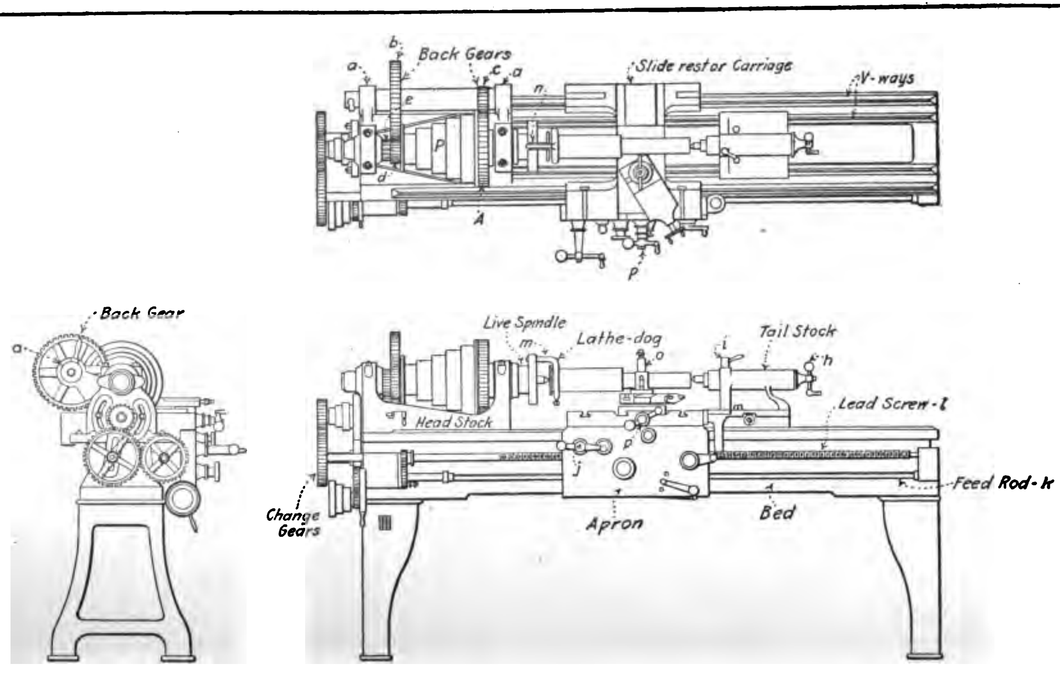


FIG. 47. STANDARD ENGINE LATHE

running the entire length of the lathe, which may or may not be a part of the main casting. The bed should be not only strong enough to carry the bending and twisting strain due to the cutting action, but stiff enough to have no appreciable springing even under the heaviest load. The ways must be straight and truly parallel, and the head- and tail-stocks parallel and in line.

Head-Stock.—The head-stock at the left-hand end of the lathe is either cast or otherwise permanently secured to the bed. It carries the live spindle and the driving mechanism. A cross-section of a head-stock is shown in Figure 48. It has two adjustable, accurately made bearings in which the live spindle runs. This is driven by a large gear, A, which is keyed to it. The stepped driving pulley, P, runs freely on this spindle; when the lathe is used for light fast cuts a locking pin, B, secures the cone pulley to the gear, A, and drives the spindle direct. For heavy cuts, when slow speed and great power are needed, the back gears are used. These are shown in Figures 47 and 48. They are usually on the same level as the spindle and directly behind it, as in Figure 47. In Figure 48, they are drawn in a false position above, in order to bring them into the plane with the picture. The bearings, c, for the back gear shaft are part of the head-stock, and the shaft, which is an eccentric, carries the two gears, b and c.

Speeds.—When the spindle is driven directly by the pulley, as described above, the eccentric shaft is turned back, and the back gears are thrown out of mesh with the gears, d and A; otherwise the mechan-

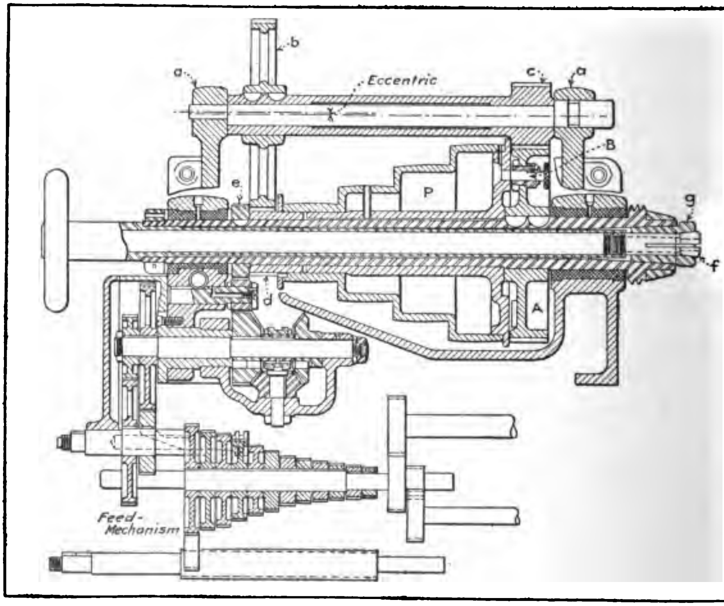


FIG. 48. CROSS-SECTION OF HEAD STOCK
Pratt & Whitney Co.

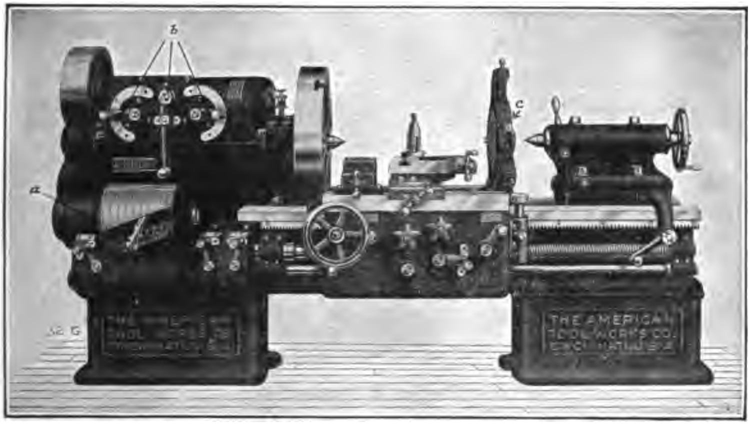
ism would lock and be inoperative. When the slow speeds are required, the locking pin, B, is withdrawn so that the cone is no longer connected with the driving gear, A, and is free to rotate on the spindle. The eccentric back-gear shaft is then turned forward to the position shown in Figure 48, throwing the larger of the back gears into mesh with the gear, d, carried on, and rotating with, the cone pulley, and throwing the smaller one, c, into mesh with the main driving gear, A, on the spindle. The power is then transmitted around through the back gears and back on to the spindle. If there are four steps on the cone

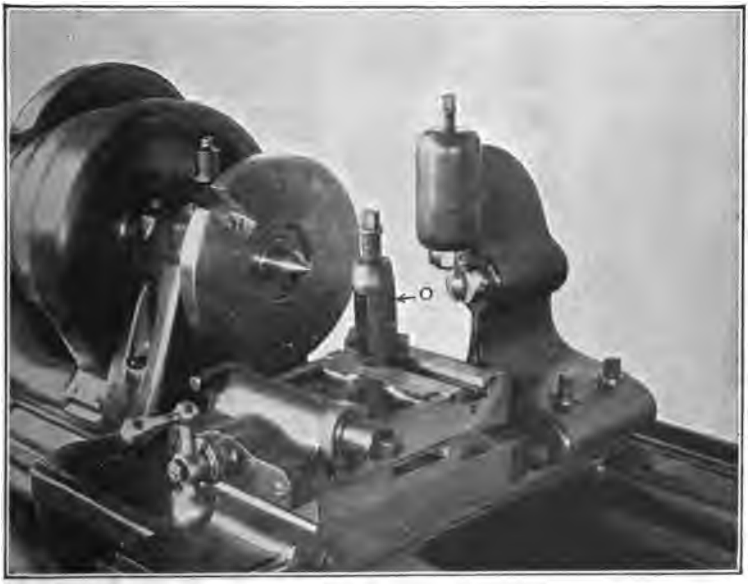
pulley, as shown in Figure 48, four speeds are possible on the direct drive, and if the lathe is thrown "into back gear" four more are possible. The speeds are usually so arranged as to be in geometrical progression. With very large and heavy lathes there may be two back-gear shafts—such lathes are said to be tripled-geared. Between the cone-pulley gear and the left-hand bearing is a small gear, e, keyed to the driving spindle from which the feed mechanism is taken.

Spindle and Tail Stock.—The main driving spindle is usually hollow. This permits cutting operations on bar stock which is slipped in through the left-hand end of the spindle and is grasped by the hollow tube shown. This tube has on its right-hand end spring jaws, f, which are drawn together, clamping the bar close to the cutting point when the hand wheel at the extreme left is turned. Instead of this spring collet, as it is called, a solid plug may be used, and the surrounding collar, g, engaging it may be split. The hand wheel may then be used to spread the collar so that it can be used as an expanding chuck to hold and center work that has a hole in it, the piece being slipped over the collar and the collar expanding until the work is firmly held. The tail-stock is shown on the right in Figure 47. This is adjustable, as a whole, lengthwise on the ways of the bed to accommodate different lengths of stock. A finer adjustment of the dead center is operated by the hand wheel, h, at the extreme right. After the work is set, the handle, i, on the top of the tail-stock locks the center in position.

Slide Rest.—The slide rest, or carriage, shown between the head- and the tail-stock, carries the tool post which holds the cutting tool. The rest has a motion lengthwise of the bed and may be operated by the hand wheel, j, or by a clutch mechanism, which engages the feed rod, k, and throws in the power feed. The rate of the power feed may be controlled by changing the gears at the left-hand end of the machine. For screw-cutting, a screw, l, is provided known as the lead screw, which gives the required traverse to the carriage. The same screw might be used for the feed and for thread-cutting, but as thread-cutting is an accurate operation, this function is dissociated from ordinary feeding and performed by a separated lead screw. The proper rotation necessary to give the cutting tool the required feed is obtained through change gears.

Change-Gear Box.—In the standard type of engine lathe used for many years the change gears were exposed at the left-hand end of the lathe, as in Figure 47. In the more modern lathes these gears are collected in a "change-gear box" at the side and in front of the headstock, and the handle, a, shown in Figure 49, which projects forward, enables the operator to make a rapid selection of the proper combination of gears required to give the lead desired. The two handles to the right of the gear box operate the change gear for the feed. The apron is the flat plate mounted on the slide rest which drops down over the front of the bed and carries the various feed attachments that connect the feed rod and lead screw with the carriage. A proper combination of the change





FIGS. 49 AND 50. HIGH-DUTY LATHE

The upper view shows a 24-inch lathe with 8-speed geared lead for single pulley belt drive. Below is shown details of carriage, tool post, and follow rest of a Pratt & Whitney Lathe.

gears will permit the cutting of either right- or left-hand screw threads. The cone pulley is driven from a countershaft which is usually hung from the ceiling over the lathe and carries a similar cone with the ends reversed from the one on the lathe spindle.

Single Driving Pulley.—One of the recent developments in tool construction is the use of a single driving pulley running at a constant speed. The speed variations of the lathe spindle are obtained by additional gearing in the head-stock casing operated by the levers, b, shown on the front of the casing above the change gear box in Figure 49. Lathes equipped with this type of drive do not need a cone pulley countershaft, and they are especially adapted to individual motor drives with a constant-speed motor.

Mounting the Work.—The work is ordinarily mounted on the centers carried in the head- and tail-stocks. The piece is driven through a lathe dog, m, Figure 47, which is clamped on the piece and has an arm that is bent to the left and engages a slot, n, in the faceplate, shown in Figures 47 and 50. For short pieces the tail-stock is frequently not used. In this case the face plate on the end of the live spindle is replaced with some form of chuck similar to that shown in Figure 51. In such chucks, a long bar of stock is put through the hole in the spindle and grasped by the three jaws, or short pieces, which have a hole through them, may be carried on the stepped faces shown on the jaws. The steps, a, a′, are used to decrease the amount of motion that it is necessary to give the jaws, these being arranged to

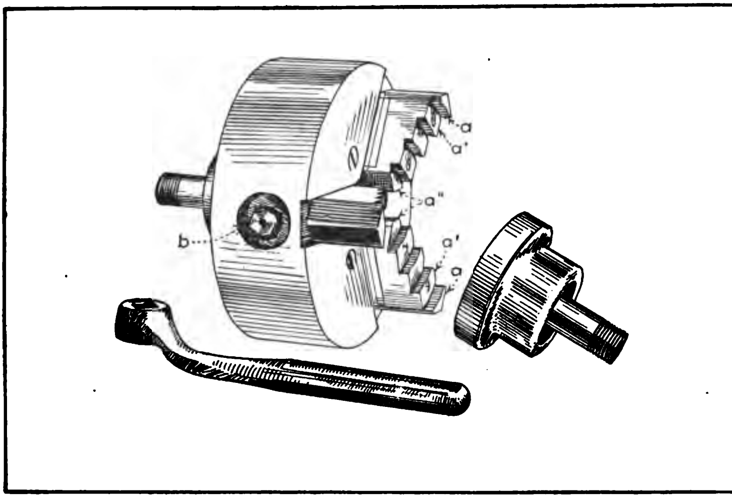


FIG. 51. LATHE CHUCK

have a motion little more than the distance between steps. If the work is slightly smaller than the capacity of the outermost step, a, the jaws are run out and the second set of steps, a′, is used—and so on to the smallest set, a″.

In the simplest form of chucks, each jaw is operated by an independent screw on the periphery of the chuck. This entails care and time on the part of the workmen in centering work. In the more refined forms of chucks, all of the jaws are operated from any one of the adjustling screws, b, there being one opposite each jaw, so that they may be moved in and out simultaneously from whichever adjusting screw happens to be in the front of the chuck. In many chucks, the jaws are reversible in the head so that

they may be used for exterior as well as interior work.

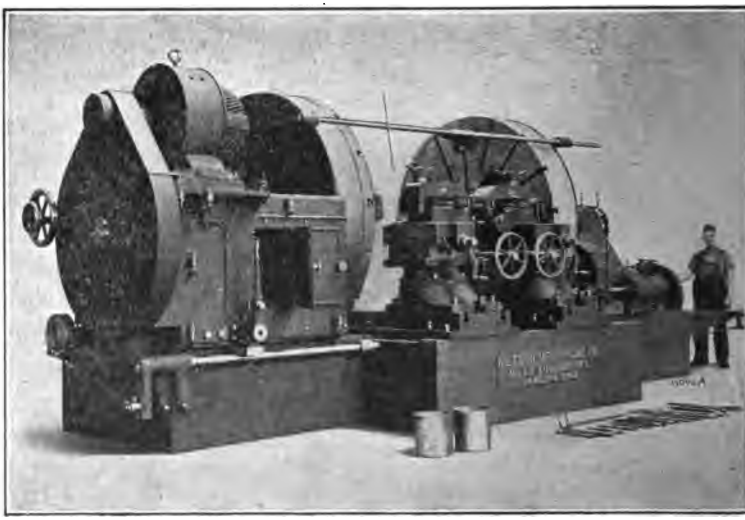
Tool Post.—The construction of the tool post, o, is clearly indicated in Figures 47 and 50. The slide rest that carries it has a feed lengthwise of the bed as a part of the general movement of the carriage, and a crosswise feed operated by the handle, p, shown in front. Compound slides are arranged to swivel at an angle horizontally, and have an independent power feed for the tool post at this angle. This gives a convenient means of turning conical surfaces. Long cones or tapers are cut much more accurately by what is known as the taper attachment. This consists of a straight edge, carried usually at the back of the bed. The cross slide carrying the tool post is attached to a block sliding on this straight edge. If the straight edge is set at the desired angle, the tool post will move in and out uniformly as the carriage is fed lengthwise, thus generating very accurately the taper desired.

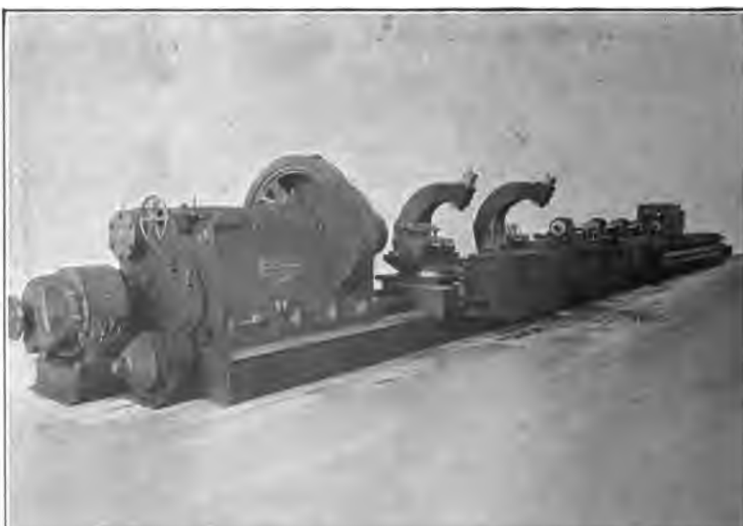
In long, slender work it is desirable to guide the piece between the centers, to prevent its springing under the pressure of the cutting tool. For this purpose a steady rest is provided, similar to the one shown at c in Figure 49, which consists of a circular frame with three sliding pieces that can be adjusted in and out from the center to bear on the work and hold it in position. It is often better to have the guide close to the tool, and to follow it as it makes the cut. In this case, it is called a follow rest and is mounted on the carriage directly behind the cutting tool, as shown in a modified form in Figure 50.

Special Lathes.—There are many forms of lathes designed for special purposes, the proportions of which differ materially from those shown. A gap lathe is one with a gap or sag in the bed in the zone of the face plate which gives a combination lathe capable of turning long work of small diameter, or short work of large diameter. Another type of lathe has two sets of centers at different heights from the bed. For work of small diameters the lower set of centers is used, and for an occasioal job of large diameter the upper set of centers is employed. Such a tool is essentially a jobbing machine, and is not to be recommended for ordinary work.

Figure 52 shows a car-wheel lathe, for turning locomotive driving wheels. In this lathe the tail-stock has been replaced with another head-stock and there are two tool posts so that the wheels, mounted on the axles, are swung on centers and driven from both sides, and cuts are taken on each wheel simultaneously. This view shows the type of face plate used on large lathes, with T-slots in the face, which are used to secure the work. Figure 53 shows a lathe of the very largest type used for boring and turning a 100-inch gun. This machine is over 185 feet long, each carriage weighs 125 tons, and the complete machine weighs 800,000 pounds.

Lathe Operation.—Care should be used in drilling the center-holes that are to carry the work. These should be concentric, and the conical surfaces that bear on the lathe centers should be cut at the same angle as the centers. It is often necessary to do turning operations that shall be concentric with a hole





FIGS. 52 AND 53. ABOVE: CAR WHEEL LATHE. BELOW: LARGE GUN LATHE

Niles-Bement-Pond Co.

already formed in the piece. Work of this character is often done on an arbor, which is a bar carried on the lathe centers and driven from the face plate. The piece is mounted directly on this arbor, which may be made expanding, to grasp the work in a manner similar to that described in connection with the chuck. If they are properly mounted, the subsequent operations will have a correct relationship to the bored hole. Pieces too large for a chuck which are comparatively short and large in diameter, are clamped directly to the face plate by means of the T-slots already referred to.

Boring may be done on the turning lathe by mounting the work on the face plate and reaching in from the end with a boring tool carried in the tool post. This can be done, however, only for holes that are readily accessible from one end. When the hole is long, the work may be mounted on the carriage and a cutting tool may be mounted on a bar carried between the two centers and driven from the face plate. If the carriage is moved along the bed, the work may be fed past the tool, and the hole may be bored. Large lathes may be fitted with a special boring bar provided with means of feeding the cutting tool along its length. In this case, the work is clamped to the lathe bed and the tool is fed past it. In general, however, work of this character is performed on boring machines, which are more conveniently adapted to this type of operations.

Eccentric work, such as crankshaft pins, may be turned on a lathe. The ordinary lathe can turn only round work that is concentric with the live spindle.

To turn a crankshaft pin, therefore, the main body of the crank is set "off center" by an amount equal to the crank throw, and firmly clamped in that position. This puts the portion to be turned in line with the lathe centers.

Spherical work may be done on a lathe if the work is revolved as usual and the tool is given a circular motion in a plane about a point lying in the axis of the lathe. In heavy work, frequently several tools are mounted on the tool post, one behind the other, the successive tools being set to take up the cut where the previous one left it—the last is the finishing tool. In this way heavy reductions can be made in one pass of the carriage.

Knurling is properly a rolling process, not a cutting one. This is performed by pressing two hardened steel rollers, mounted in the tool post, against the revolving work and rolling the impression of grooves on the face of the rolls into the surface of the work. The operation is a very common one in tool rooms where the handles of gauges are roughened in order that they may be grasped the more easily. The small diamond-shaped knurling which is so common is done by two rollers with spiral grooves, one right-hand and one left-hand. The impressions of these rollers crossing each other form the diamond-shaped projections.

Thread-cutting, one of the most important operations performed on the lathe, will be taken up in the chapter devoted to that subject.

CHAPTER XIV

TURRET AND AUTOMATIC LATHES

The Turret Principle.—While the engine lathe is one of the best machines ever designed for general or jobbing work, its use requires a skilled operator, and the time required in changing and setting tools and in measuring length and depth of cuts is usually largely in excess of that required to make the cuts themselves. Both the skill and the time required to do lathe work may be reduced, with a consequent saving in the cost of production, by the use of the turret principle. In the turret lathe a slide is substituted for the tail-stock, and mounted on this is a revolving member, or turret, which has certain stops or positions, usually from four to six. The cutting tools are mounted on this turret, and are accurately set with reference to the work. The work—which may be either castings or forgings held in some form of chuck, or barstock, which is fed through the hole in the live spindle—is carried entirely from the head-stock end.

The sliding carriage is fed forward, either by hand or automatically, to a definite stop which limits the length of the cut; the carriage is then withdrawn and brought forward again. This action indexes the turret to the second position, and brings into action a

second tool which has been definitely set for the operation it performs. The second motion also comes to a definite stop, set to correspond to the second cut and independent of the one previously made. Successive movements of the carriage bring the other tools mounted on the turret into action in a similar way; each motion has a definite stop arranged for that cut. In most turret lathes auxiliary side tools are carried to definite stops on a cross slide mounted on the bed between the head-stock and the turret, which may also be either hand-operated or automatic.

Turret Lathe vs. Engine Lathe.—The use of this turret principle greatly reduces the time necessary to set the tools and so on. With an engine lathe the operator will place the tool in the tool post, after the work has been properly mounted on the face plate, will make a trial cut, caliper the piece, adjust the tool, and repeat the process until the correct size is reached. He will then start the cut. As he approaches the end of the cut, he will stop the machine and measure the work to see whether the cut is long enough or deep enough, repeating the process until the correct length of cut has been made. Whenever it is necessary to change the tool to perform some other type of operation, the whole process must be repeated. This round must be gone through for every piece made, and it is this work which is eliminated by the turret lathe.

In the latter type of lathe the various cutting tools are placed in position by the tool-setter, who is a skilled man. This work is done with care, and one or two trial pieces are run through. When the machine

has been "set up," it is turned over to the machine operator, who has only to clamp the successive pieces in the chuck and feed the turret and tools forward to make the cuts. In the case of automatic lathes for bar stock, he does not even have to do the latter. His work becomes merely that of keeping the bars supplied to a number of machines, each of which will automatically feed forward the required amount of bar stock, clamp it, perform the successive operations, cut off the finished piece, and feed forward stock for the next piece. The work of setting the tools and measuring the length of feed is consequently done but once—by the tool-setter—and the cost of doing it, instead of being carried by each piece, as in the case of the engine lathe, is distributed over the entire run.

Hand and Automatic Turret Lathes.—The turret principle was the first radical improvement on the lathe after the work of the pioneers, Maudslay, Roberts, and others. There were probably a number of lathes operating on the turret principle prior to 1850, but the first one which was regularly built and placed upon the market was brought out by Jones & Lamson, then of Windsor, Vermont, about 1855. The principle was applied to the manufacture of guns, sewing machines, and other interchangeable articles. For about twenty years turret lathes were hand-operated, and required an attendant for each machine. About 1875 Christopher M. Spencer, of Hartford, developed the idea of automatic operation, in which the various motions of feeding the work, closing the chuck, operating the turret and cross slide, and cut-

ting off, were all controlled by a single camshaft mounted in the body of the lathe parallel to its axis and making one revolution for the complete cycle of operations. This invention greatly increased the capacity of the lathe and enabled an operator to tend a number of machines.

Multi-Spindle Automatics.—The next increase in the capacity of the lathe came about twenty years later, when Mr. Henn and Mr. Hakewessel developed the first multi-spindle automatics. In both the hand and the automatic single-spindle lathe the work revolved, but remained in the same position, and the tools were brought to bear upon it in succession. The time required to finish a piece was, therefore, that required for the sum of the various operations. In the multi-spindle automatic, the axis of the indexing member is horizontal, and parallel to the axis of the lathe; and there are several live spindles corresponding in number to the number of tool positions. Each of these spindles carries a bar of stock which is being operated upon, and all the tools are cutting simultaneously. When the longest cut is finished, either the tools or the spindles are rotated to the next position and the operation is repeated. A bar is fed forward for the first operation, and then indexed progressively through the successive positions until the piece is completed. Either the tools or the spindles may be indexed. With this type of lathe, the time required to finish the piece is reduced from the total time of all the operations to the time required for the longest individual operation on the piece.

Hand-Operated Turret Lathes.—Of the various types of turret lathes, the simplest is the plain hand-operated machine, shown in Figure 54. This is used for small and light work. In the one illustrated, the oil pan and bed are in one casting. As stiffness and perfect alignment are essential in all turret work, the head is also frequently cast solid with the bed, although the one shown is a separate casting. To increase the stiffness, the small end of the cone pulley is pointed toward the right, which permits a firmer support for the main bearing of the spindle. The spindle bearings are babbitted. Two-speed counter-

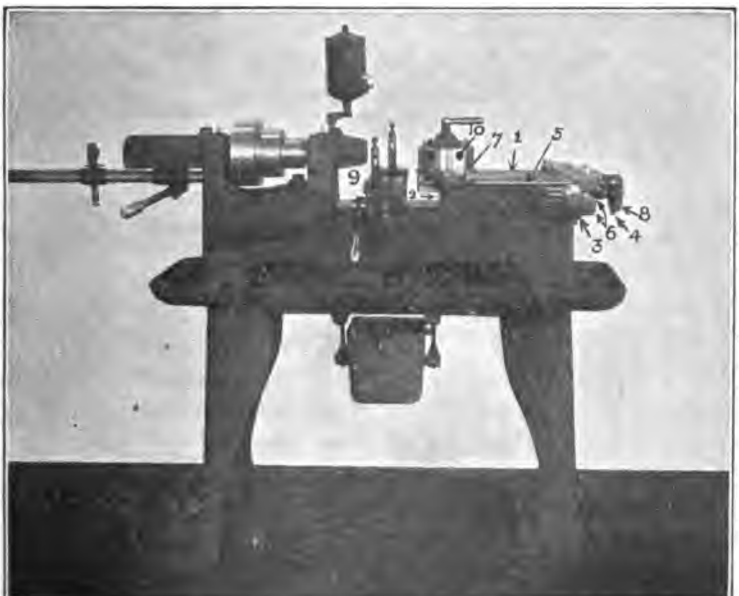


FIG. 54. HAND-OPERATED TURRET LATHE
Pratt & Whitney Co.

shafts are used either for forward and reverse or for two speeds forward when opening dies are used.

The turret slide, 1, is mounted in a block, 2, which is adjustable longitudinally along the bed to accommodate different lengths of work. The turret revolves on a conical central stud, or pin, fixed on the turret slide. The bolt which locks the turret in its various positions is located horizontally in the slide, and is hardened and ground; it is supported for its entire length, and engages the turret directly under the cutting tool. The index ring on the turret, which the locking bolt engages, is also hardened and ground and is securely doweled and bolted to the under side of the turret. The stop mechanism which limits the feed for the various positions of turret, is clearly shown. The stops, 6, are short steel bars located on a radius in a steel bracket, 3, which is on the front of the block, 2. An oscillating lever, 4, on the shaft, 5, engages one or other of the adjustable stops, 6, according to the position of the turret. The position of the arm, or lever, 4, is controlled by a cam, 7, on the lower periphery of the turret. As the turret revolves from one position to another, this cam, acting through the shaft, 5, brings the arm, 4, into position for contact with the proper stop. The arm, 4, is relieved of any strain by being backed up by the projection, 8, which is a part of the turret slide, 1.

In small machines of this character the turret slide is operated by a single hand-lever as shown, and the indexing of the turret is done by the movement of the slide. A cross slide, 9, carries the forming and cutting-off tools, one in front of the work and the

other behind it. The slide is adjustable lengthwise on the bed between the head-stock and turret slide, and can be clamped to the ways in the position desired. The feed of the slide is by hand lever through a rack and pinion, and is accurately governed in both directions by means of adjustable stops. The bar stock, which is not shown in Figure 54, is fed forward by means of the hand lever on the left.

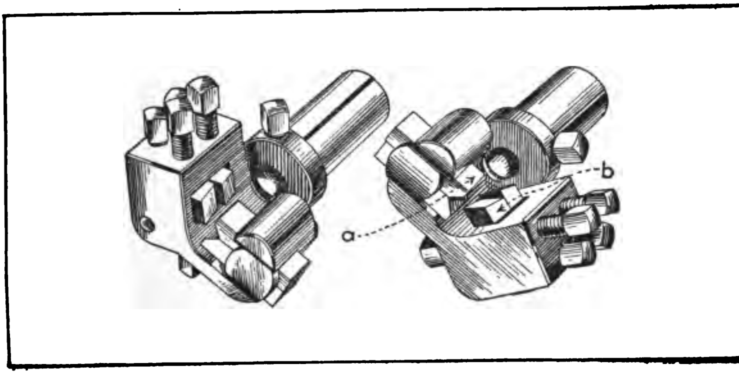


FIG. 55. MULTIPLE BOX TOOL

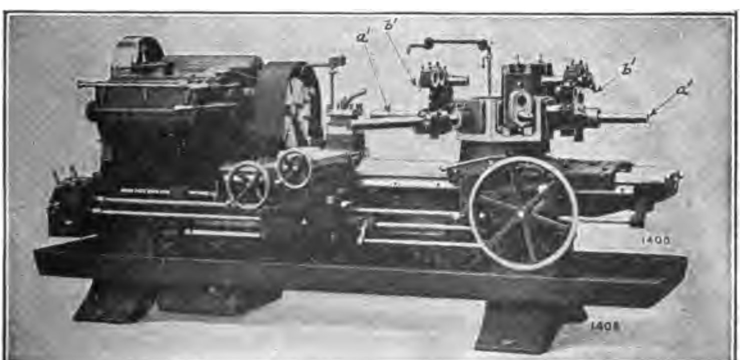
Pushing this handle to the left unclamps the chuck and moves the feeding mechanism back along the bar the distance required for the next piece. The return movement of the handle brings the bar forward this amount, and at the end of the motion the accurately finished and hardened chuck jaws clamp the work concentrically with the spindle.

The cutting tools are carried in the holes, 10, shown in the turret. Two of these tools are shown in Figure 55. The box tool, A, is one of the characteristic tools used in turret work. As there is no tail-stock on the

turret lathe, a heavy side cut on a long bar would tend to spring it out of position. To prevent this, an adjustable stop, a, is provided which is carried on the tool body immediately opposite the cutting tool, b. Tools of this character are used in a wide variety of forms.

Gisholt Lathe.—A turret lathe of a much more complex type is the Gisholt lathe, shown in Figure 56. This machine was a pioneer in applying the turret principle to large and heavy work, and is built in sizes having a swing as large as 41 inches. The spindle is bored to enable the use of barstock, but the machine is more commonly used on castings and forgings held in a chuck. This lathe was the first to employ the pilot bar principle in heavy turret work. The pilot bar is very useful in relieving the machine of much of the strain due to heavy cuts.

The first operation on the piece is to establish an accurately bored hole in the piece to be machined. Pilot bars, shown at a in Figure 56 and at a′ in Figure 57, used with the succeeding operations, enter this hole and center the cutting tool, b and b′. The side strains between the cutting tool, b′, and the pilot bar, a′, due to the cut—which would otherwise extend down through the turret, along the bed, up through the head, and out upon the work—are carried by the fixture itself. The machine is therefore relieved of these strains, and the resulting work is more accurate. The axis of the hexagonal turret is inclined backward instead of standing vertical, as in other machines. This is done to enable the long pilot bars and other tools to swing clear of the operator in front. The



FIGS. 56 AND 57. ABOVE: TOP VIEW OF A GISHOLT LATHE.
BELOW: WARNER & SWASEY LATHE

machine is equipped with a cone pulley and a back gear, and the head-stock is cast solid with the bed. A sliding carriage between the head-stock and the turret has a revolving tool post, designed to hold four cutting tools, which is in effect an auxiliary turret.

Any one of these tools may be brought into cutting position by revolving the tool post, and each is independently adjustable for height and is provided with an automatic stop. The tool post has an independent power cross feed, and the carriage is also fitted with an attachment for turning tapers, and with a support for rigidly holding boring bars, drills, and so on, in line with the spindle. This is so designed that when not in use it may be swung back out of position to clear the chuck. Both the tool-post carriage and the turret slide are screw-cutting, and the power feed may be varied without changing the gears. The carriage and slide are also provided with clamping devices to bind them rigidly to the ways at any desired location. This machine has been in successful use for many years and has had a wide influence on machine shop practice, extending the use of the turret principle to the machining of such pieces as pistons, cylinder heads, flanges, couplings, and pulleys. The Gisholt Company has also developed a lathe in which the operations when once the piece has been chucked in place are entirely automatic. This last machine is of the single-pulley, one-speed type.

Warner and Swasey Lathe.—Figure 57 shows another large turret lathe, built by the Warner & Swasey Company. The turret, or revolving member,

in this machine is a large, hollow hexagon mounted on a saddle, or slide. This form permits the attachment of much heavier tools than allowed by the holes shown in Figure 54. Several of the tools shown are provided with pilot bars just described in connection with the Gisholt lathe. This lathe, like the Gisholt, may be used either for bar-stock work or for castings and forgings; simultaneous operations may be performed by the turret and by a carriage with a square tool post which can be indexed to four positions.

The saddle, or main slide, is mounted directly on the bed, and both the saddle and the carriage have power feeds or may be operated by hand wheels; the various motions are controlled by independent automatic stops. The head and the bed are cast in one piece. There is a constant-speed, single-pulley drive, the various changes of spindle speed being obtained by a gearing enclosed in the head and running in oil. The machine can be belted directly to a line shaft, or can be driven by a constant-speed motor. The changes of feed for the carriage and the main turret saddle are controlled by a feed box at the head end. This lathe will handle round bar stock 3½ inches in diameter, or a maximum of swing for face-plate work of 21½ inches. The maximum length turned is 44 inches, and the maximum horsepower required is 10.

Hartness Flat-Turret Lathe.—Another type of turret lathe is the Hartness flat-turret lathe, which was invented about 1891 (see Figure 58). The characteristic feature of this machine from its earliest appearance has been the flat circular plate mounted on the

saddle, which carries the various tools and tool-holders on its upper surface, thus replacing the usual barrel turret mounted on a stud and carrying the tools around the periphery. The advantage of this construction is that the tools do not overhang their support, and the whole construction is very rigid as the flat turret plate is secured to the saddle by an annular clamp which holds it rigidly at all points. The turret is automatic in action, turning as the tools clear the work, and it may be set so as to skip one or more of the indexing positions when desired.

As in other types of turrets, the locking bolt is on the outer edge, directly under the cutting tool. In the earlier forms of this lathe, the crosscuts were obtained from a saddle between the head-stock and the turret. In the later types the carriage is done away with, and the head is provided with a cross motion. As in the machine just described, there is a single-speed driving pulley, and the changes of speed are derived from change gears, which run in oil inside the head casing. The flat turret, which gives this lathe its advantage, limits it to work of moderate diameter; its natural field is for threading and turning large studs, bolts and arbors. The size of work done ranges up to 3 inches in diameter and 36 inches in length.

Instead of one working spindle and a circular turret with six positions, this type of lathe is also made with two working spindles and a turret which is square. Each face of the square turret carries two sets of tools, and two similar cuts may be carried on simultaneously. If the turret is indexed four sets

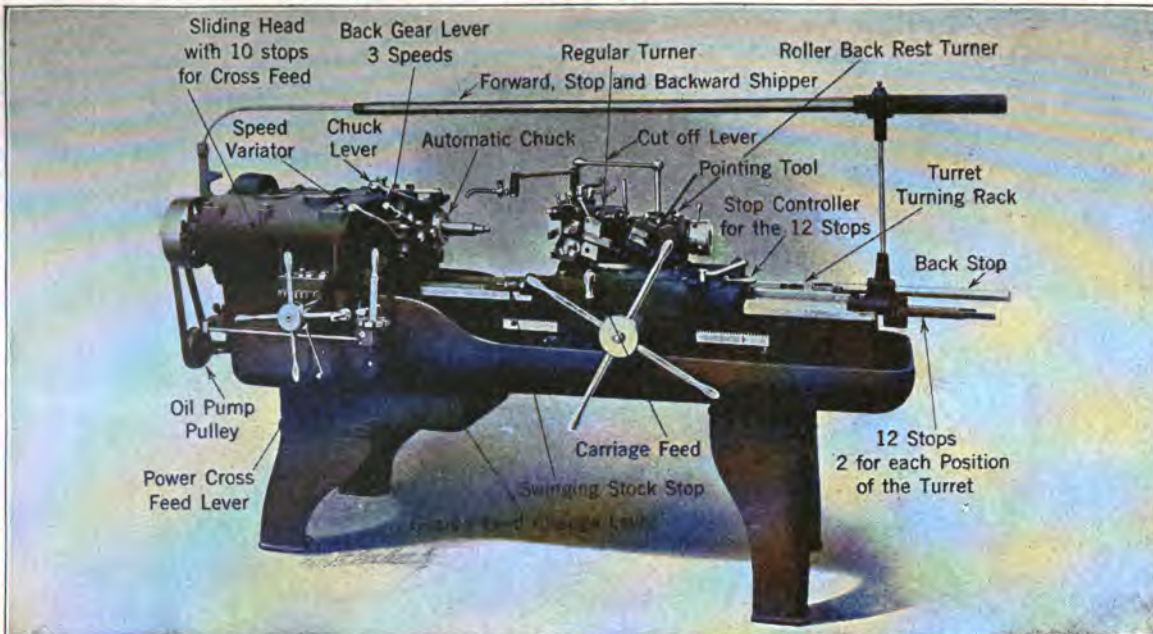
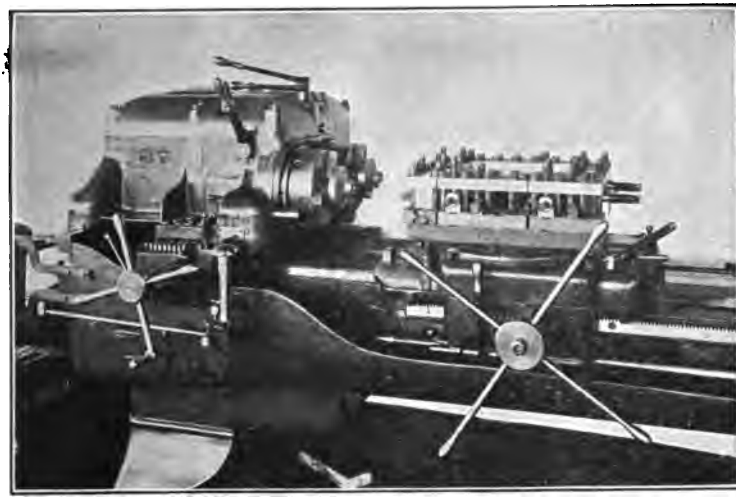


FIG. 58. HARTNESS FLAT TURRET LATHE

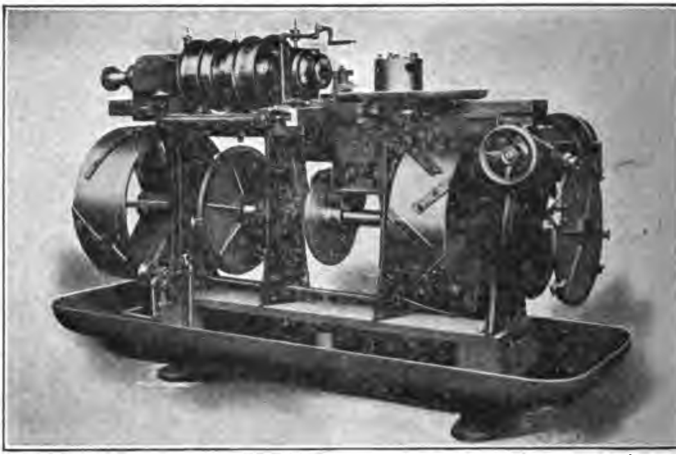
of tools may be used. Figure 59 shows a typical set-up for this type of machine.

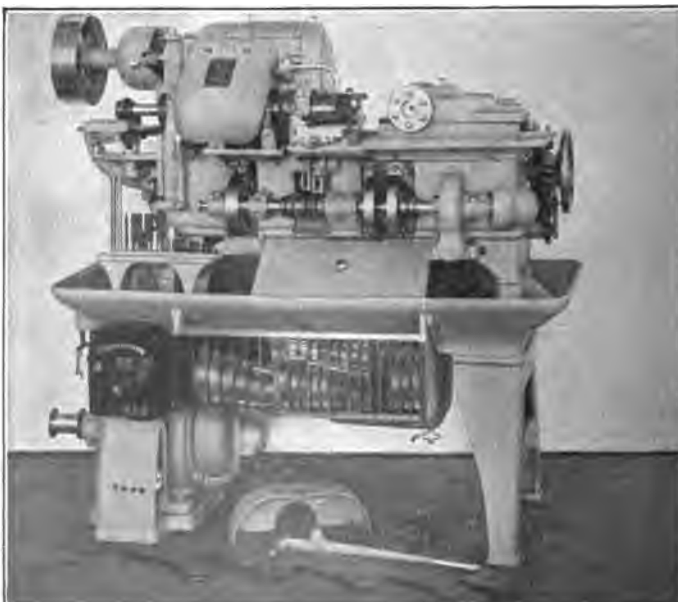
An automatic chucking and turning lathe which has been very successful, is the Potter & Johnson machine, shown in Figure 60. In this machine, rigidity for the turret tools is sought in another way. A vertical turret is used, but the stud or pin upon which it revolves is braced on the top by a heavy overhead support which extends back to the rear of the turret slide. The machine has a geared head with a single-pulley drive, cross slide with double, independent, adjustable tool blocks, and an automatic back facer bar operated through the spindle. The chuck is 16 inches in diameter and the hole through the spindle is 3½ inches in diameter.

Principle of Automatic Lathes.—The first automatic lathe, as mentioned in the beginning of the chapter, was developed by Spencer for the Hartford Machine Screw Company. A later form of this lathe is illustrated in Figure 61 which shows very clearly the general principle underlying the construction of nearly all of the full automatic lathes. The driving spindle, cross slide, and turret are present, as in the simple type of turret lathe in Figure 54. The control that makes them automatic is derived from the long cam shaft running through the frame, parallel to and below the main center. This shaft revolves slowly, making one revolution for each complete cycle of operations. The large drum to the left controls the operation of the mechanism that feeds the bar stock forward each time a piece is completed. This feeding is done by means of the strips bolted on the face,



FIGS. 59 AND 60. ABOVE: HARTNESS DOUBLE-SPINDLE LATHE. BELOW: POTTER & JOHNSON LATHE





FIGS. 61 AND 62. AUTOMATIC SCREW MACHINES
Upper: Hartford Machine Screw Co. Lower: Brown & Sharpe Mfg. Co.

which engage a pin in the mechanism above. The plate under the driving pulleys operates the belt-shifting mechanism by means of the dogs shown on the edge. The timing of the belt-shifting is accomplished by sliding these dogs to the required position around the edge of the plate. The next cam controls the motions of the cutting-off tool located in the slide immediately above it. The large cam to the right controls the motions of the turret carriage. The worm wheel drives the cam shaft, and the plate at the extreme right controls the fast and slow speeds of the cam shaft.

In this machine, as in those previously described, the axis of the turret is vertical. A second position is possible—that is, the axis of the turret may be horizontal, and at right angles to the line of the driving spindle, the rotation being in a vertical plane. This position is utilized in the Brown & Sharpe automatic screw machine, shown in Figure 62. This machine is fitted with a motor in the base, driven by a short belt through the constant-speed pulley shown at the left of the head-stock. A spring-actuated idler pulley near the motor shaft (not shown) maintains the proper belt tension. In this machine the cam shaft, controlling the motions, is in front of the bed, and the turret is at the forward end of the turret slide. The various tools, threading dies, and so on, are arranged around the face of the turret in the six positions, and are held in place by bolts which appear on the front face of the turret.

In the third position of the turret the axis is also horizontal, but is parallel with the axis of the driving

spindle instead of at right angles to it, as in the Brown & Sharpe machine. An example of this is given in Figure 63, which shows a plan view of the Cleveland automatic lathe, in which the turret takes the form of a drum, with five tool positions that rotate in a plane at right angles to the axis of the machine. The cam shaft in this lathe is located in

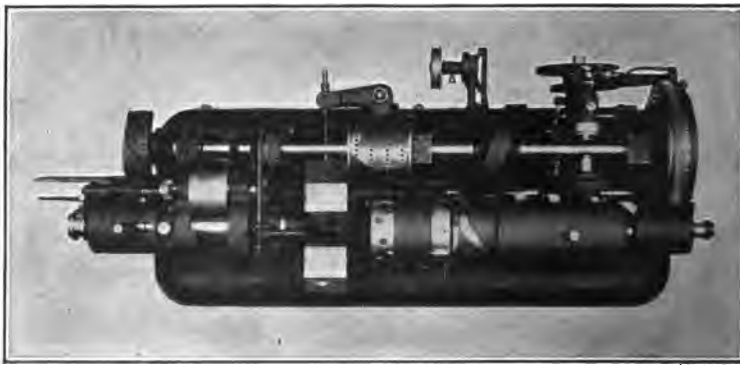
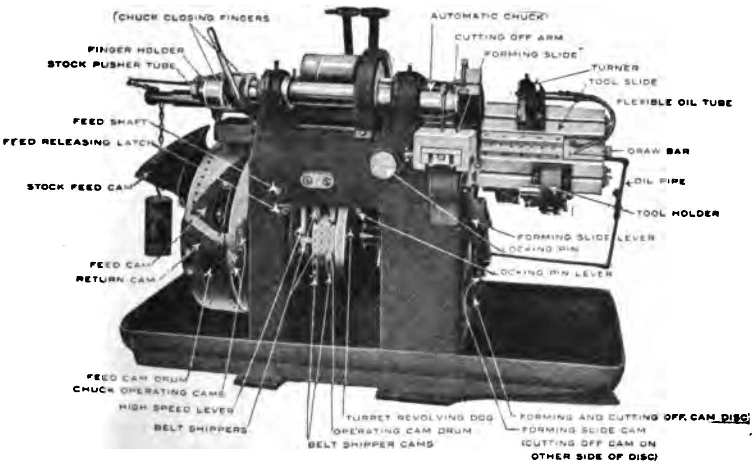


FIG. 63. TOP VIEW OF A CLEVELAND AUTOMATIC LATHE
Cleveland Automatic Machine Co.

the rear. The various drums are clearly shown. The large wheel at the right is called the regulating wheel and carries ten segments, two for each hole in the turret, which can be adjusted while the machine is in motion to suit the feed requirements of each of the five cutting tools.

Gridley Automatic Lathe.—The Gridley automatic lathe, shown in Figure 64, another horizontal machine, represents a more radical departure from the old standard lathe design. The long bed characteristic of all the previous machines is shortened into a more or less box-like frame, and the turret, instead of



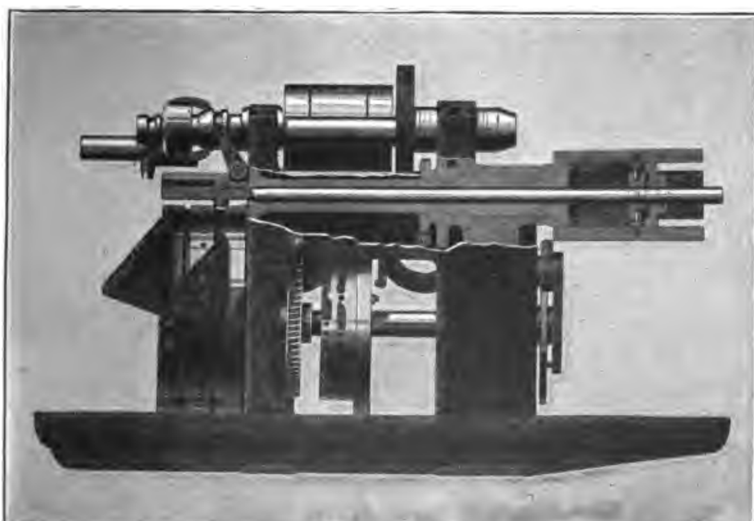


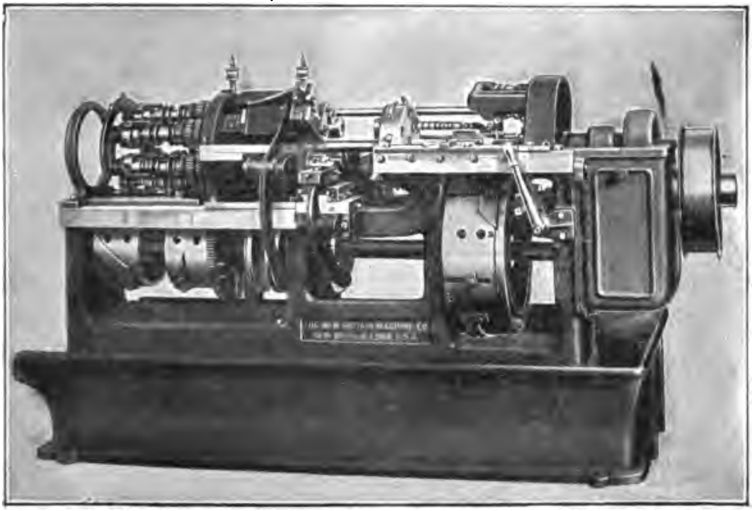
FIG. 64. GRIDLEY AUTOMATIC LATHE—TURRET WITH HORIZONTAL AXIS

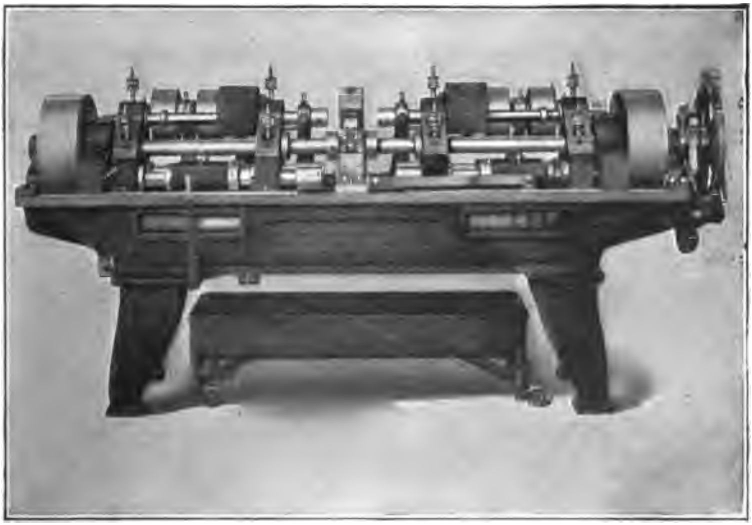
Above: Location of parts. Below: Sectional view through the turret, showing turret supports and tool slides. The National Acme Co.

being on a carriage on top of the bed, overhangs at the end. The various tools are carried on the faces of the turret, and the feed is parallel to its axis. The cam shaft controlling the operations, which makes the machine automatic, is clearly shown in the frame below; the large drum at the left controls the turret feeds through a long draw-bar and a pin which engages the cam at the left. The cam in the middle revolves the turret and operates the belt-shifting mechanism. The cam at the right operates the cross slide and cutting-off tools.

Multi-Spindle Automatics.—The longitudinal position of the turret axis is the only one that permits of the use of multiple spindles. This fact is made use of in the Acme, Gridley, New Britain, and other machines. Figure 65 shows a multi-spindle lathe of this type. In this machine an indexing head, which corresponds to a turret, carries six spindles, each of which may contain a bar stock to be cut. The tool carriage carries an equal number of cutting tools in alignment with each of these revolving shafts. Each of the cutting operations has an independent feed, controlled by the operating cams, and all the cutting tools work simultaneously. The cutting tools include the cross-cut tools as well as those carried in the main head. When the longest cut is finished, the tools are withdrawn, and the head with all six spindles is indexed around to the next position. Then the process is repeated.

The feeding of the stock is done at one of the positions only, at each indexing of the turret. This spindle performs the first operation, the other opera-





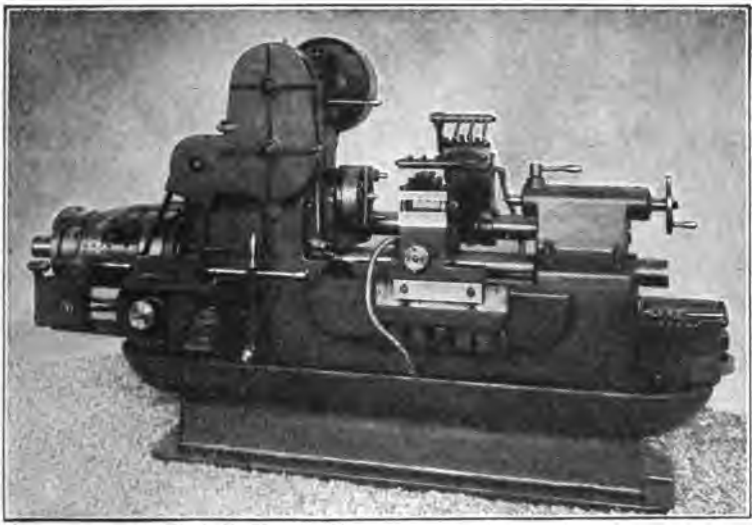
FIGS. 65 AND 66.

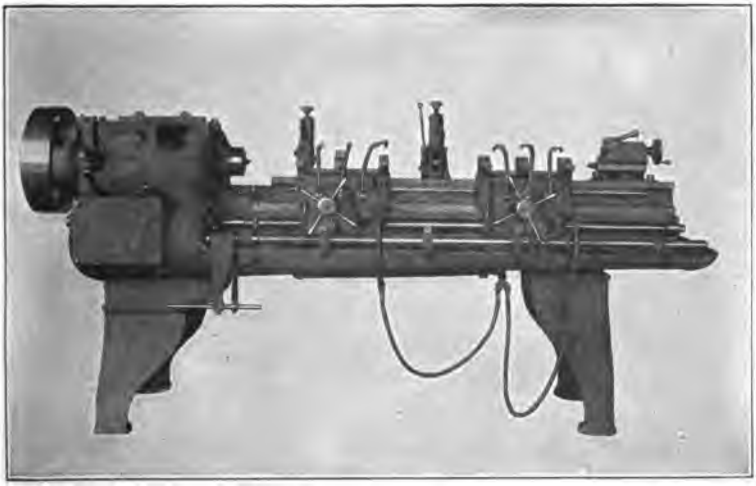
Above: Multi-spindle Automatic Lathe for Bar Stock. Below: Multi-spindle Automatic Chucking Lathe. New Britain Machine Co.

tions are performed in the successive positions, and the piece is completed at the last. A piece is therefore finished on the last spindle at each indexing. As many operations may be performed as there are driving spindles. If there are fewer operations than there are spindles the longest operation may be subdivided, half of it being done on one spindle and the remaining half on the next one. In this way, the time for finishing the piece may be materially cut down. This type of machine is intended for bar-stock work.

The machine illustrated in Figure 66 shows a type designed for chucking forgings and castings, in which the horizontal turret principle is used. Here the turret is carried in the middle on a long shaft that has bearings along the top of the machine and rotates only. There are two spindle heads, one on each side, each with three working spindles, and four positions in the turret. There are four chucks, which correspond to these four positions. While the front one is being filled, work is going on on each side of the other three positions. In this way simultaneous machining operations may be performed on two sides of such pieces as sprinkler heads, globe valves, and so on. This not only saves time, but saves a double chucking of the piece—consequently there is a more accurate alignment of the two cuts.

Fay Automatic Lathe.—In all of the automatic lathes described, the turret principle has been employed in some form. The Fay automatic lathe, shown in Figure 67, applies the automatic principle and cam control to the engine type of lathe. This





FIGS. 67 AND 68. ABOVE: FAY AUTOMATIC LATHE
BELOW: LO-SWING LATHE

lathe has a head-stock, a tail-stock, and a carriage, but they are modified to adapt them to automatic operation. It is intended for turning work which is held on centers, and especially for that class that is done on arbors, where the cuts are to be concentric with a previously finished hole. It is adapted to do straight, taper, and formed turning, straight and bevelled facing, and recessing, either singly or in combination with roughing or finishing cuts. It will not, however, do threading work, for which it is not intended.

The spindle of this lathe is a large, stiff, iron casting running in iron-to-iron bearings, and is worm-driven. This locates the machine drive at right angles with the center line of the machine, a rather unusual arrangement. The carriage, instead of sliding on V-ways on the bed, is carried on a heavy steel bar seated in the head- and tail-stock castings, which ties the tool-supporting and work-supporting members directly together. The feeding motion in this direction is governed by a former bar secured to the front of the bed. As the carriage feeds over this former it is swung up or down, and the tools are correspondingly swung toward, or away from, the work, thus controlling the contour turned. The bar is so arranged that the carriage tools are swung away from the work in returning them to their initial position after having finished a cut.

A back arm is provided for facing cuts, which may be made while turning cuts are in progress with the carriage tools. This back arm is pivoted on another bar, which is also supported in the head- and tail-

stocks. It is swung inward by a heart cam, which is geared with the main cam drum. This arm also carries a multiple tool block of the same construction as that used on the carriage. It is normally used for square facing, but may be employed for recessing, bevel facing, and for taper or form turning. All the movements of the machine are controlled by cams.

Lo-Swing Lathe.—Figure 68 shows a special-purpose lathe, for heavy production, which is another modification of the standard engine lathe. This lathe is intended to turn work of comparatively small diameter and of considerable length, which must be carried on centers. The face plate and the chuck of the ordinary lathe are discarded. The swing is thus greatly reduced, and at the same time the chances for springing in the tool carriage, the tail-stock, and so on, are lessened. There are two tool carriages, each capable of holding several tools, so arranged as to pass by the tail-stock for starting cuts and for short work. The cross-section of the bed is radically different from that of an ordinary engine lathe, and the carriage, instead of sliding on V-ways at the front and back, is carried on a strong, narrow guide at the top and front of the bed. The tool-holder is a low, solid block, resting directly on the carriage, which provides an exceptionally rigid support for the cutting tools; there is only one joint between the cutting edge and the bed. A taper attachment controlled by a template furnishes means for cutting two tapers while other cuts are in progress. One or both of the carriages may be used and each carriage may have multiple-cutting tools. While the Lo-swing lathe has

no turret, there are present the essential features of the turret, namely, the use of several tools and the preservation of the adjustment of the tools. The lathe is especially adapted for the production of axles, spindles, and other pieces that have diameters up to 3½ inches and a length of 9 feet or under.

Blanchard Lathe.—Another very interesting type of automatic lathe is known as the Blanchard lathe. It is named after its inventor, an ingenious old New England mechanic, who developed the lathe for the Springfield Armory in 1818, to be used in turning gun stocks. In this type the work is rotated at a moderate speed, and the cutting tool has an independent rotation of its own like that of a milling cutter or a saw. This cutting tool is moved in and out from the center of the work under the influence of a former, which rotates at the same speed as that of the work. As the cutting tool travels lengthwise, it can be made to reproduce accurately very irregular shapes. Two pieces of work on different centers may be made to rotate in opposite directions, the cutters used on them being operated by the same former. This will cause the former to reproduce two shapes, which will be "right and left." This device is used in making shoe lasts. The principle involved, in addition to its original purpose of turning gun stocks, has been applied in an endless variety of uses, from manufacturing wheel spokes to making hobby-horse heads. A modern form of this lathe, is shown in Figure 170.

CHAPTER XV

BORING

Wilkinson's Boring Machine.—The boring machine is closely allied to the lathe. Historically, it is the oldest of the modern machine tools. The boring machine invented by John Wilkinson, of Bersham, England, in 1775, made Watt's steam engine possible, Watt invented his engine, with the separate condenser, in 1765. A model that he made in a few days clearly demonstrated the correctness of its principle, but he was unable for ten years to build a full-sized engine that could be a commercial success. His trouble—the inability to make the piston steam-tight—was due to the impossibility, at that time, of boring a cylinder round. And it was not until Wilkinson built a boring machine with a boring bar supported on each side of the work, that cylinders could be obtained sufficiently true to make the engine a practical possibility.

From that time on, it was a success. Wilkinson's machine, at the first trial, bored a cylinder for Watt 57 inches in diameter which did not deviate from truth by more than "the thickness of an old shilling," possibly a little more than 1/32 of an inch. This was not bad work, certainly not for those days, and Wilkinson's machine may be considered as the first of

the modern machine tools for anything like large work. Maudslay's slide rest and improvements in the lathe did not come until nearly twenty-five years later. In Wilkinson's machine the cylinder was strapped to heavy oak timbers. A large cast-iron boring bar was put through the hole and carried on trunions which were mounted on the timbers at either end of the cylinder. This boring bar was rotated by power, and carried a cutting tool which was fed lengthwise as the work progressed. His machine, therefore, contained the essential elements of the modern horizontal boring machine.

The vertical boring mill seems to have been first suggested by John George Bodmer, a Swiss engineer who lived for many years in England. He described it in his remarkable patent about 1840, and called it a "rotary planer." The vertical boring mill apparently made very little impression upon English mechanics at that time, and it was left to American tool builders to develop this type of machine and to show its possibilities. For this reason, it has generally been considered of American origin, although there is little doubt that Bodmer's machine antedates the use of boring mills in this country.

Boring Mills Classified.—The term, boring mill, is often used for both the horizontal and the vertical type. This usage, however, is not followed by tool builders, who confine the term "boring mill" to the type (usually vertical) in which the work revolves and the tool is stationary except for the feed. The horizontal type, in which the cutting tool revolves, is termed a horizontal boring "machine," the essential

idea being that the term "mill" is confined to the cases where the work rotates.

Machines for boring range in size from those that handle work 12 or 14 inches in diameter, to those capable of turning work 30 and even 40 feet in diameter; the latter are among the very largest machine tools built. This wide variety of machines may be roughly classified under three general heads: Vertical boring mills, horizontal boring machines which are self-contained, and portable boring machines which are used in floor-plate work, and are picked up by a crane and moved from place to place, as they are needed, around the work.

Vertical Boring Mill versus Lathe.—The vertical boring mill is adapted to boring, turning, and facing cuts that are concentric with, or related to, a single axis. Reference to Figure 69, and also to Figure 71, will show that it is, in effect, a lathe which has been stood up on its headstock end, and that its principal elements are adaptations of lathe parts, the tailstock being omitted. The bed of the machine, a, supporting the table and resting upon the floor, corresponds to the headstock; the rotating table, b, to the lathe faceplace; the uprights, c, c, to the lathe bed; the cross rail, d, to the lathe carriage. The tool-carrying head, e, is an elaborate development of the simple tool post of the engine lathe. The machine shown in Figure 69 is very properly termed a vertical turret lathe, since the turret head corresponds closely to the turret and turret slide of the lathes shown in Figures 56 and 57, and the side tools correspond to the cross-cutting slide shown in the same figures. It

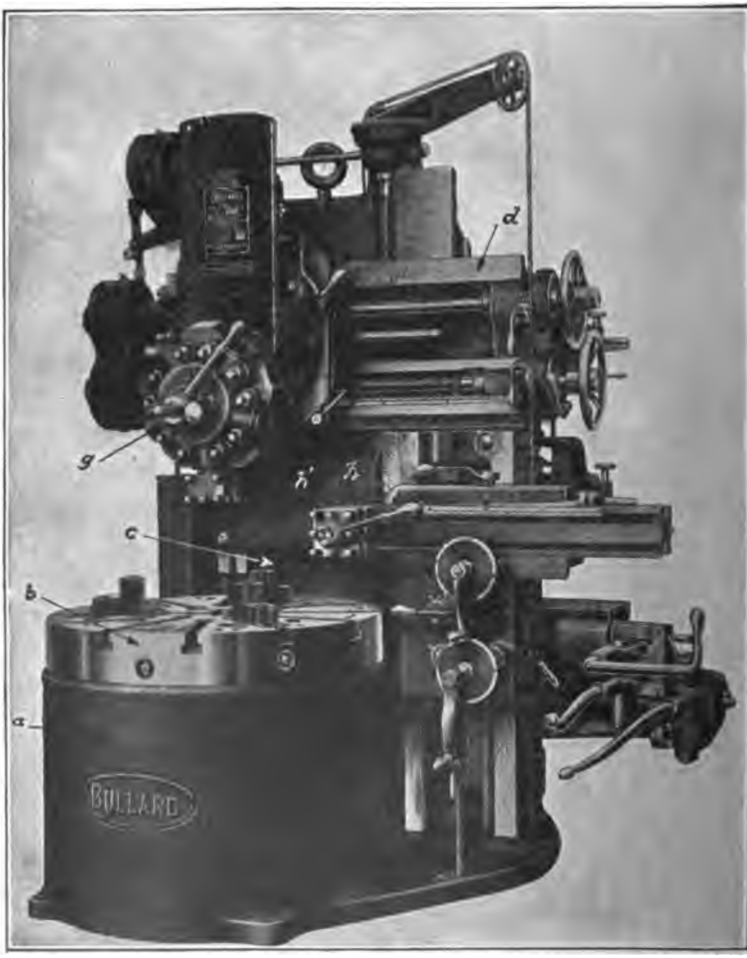


FIG. 69. VERTICAL TURRET LATHE
Bullard Machine Tool Co.

contains substantially all the elements of these machines, modified, of course, to suit their position and the different conditions of operation.

The vertical position characteristic of the boring mill gives it many advantages over a lathe for handling short, heavy work of comparatively large diameter, such as pulleys, gears, flywheels, pistons and cylinder heads, car wheels, turbine disks and casings, and so on. In the first place, it occupies very much less floor space than a lathe of corresponding size. It would be difficult to secure to the vertical face of a lathe faceplate the large castings handled in a machine of this type. It would be difficult, also, to balance such pieces, since they are frequently unsymmetrical; and the overhanging weight would produce a heavy bending strain upon a lathe spindle. Pieces of this kind, however, may be set by a crane onto the table of a boring mill with little difficulty, and may be easily centered. In other words, "it is easier to lay a heavy piece down than to hang it up." Any eccentricity of weight has little effect, as the center of gravity is almost certain to fall well within the circle of support. The very weight of the piece is a help in holding it to a boring-mill table, instead of being a hindrance, as it would be in the case of a lathe faceplate.

Vertical Boring Mill versus Planer.—Plain facing work may be done on a vertical boring mill or on a planer. Round or nearly round work may be faced to greater advantage on a boring mill. A planer cuts only in one direction, and has an idle return stroke. It therefore works at a disadvantage on cuts, on

which a boring tool could be working continuously, or nearly so. On long, narrow faces the advantage is reversed, as by far the larger part of the time a boring mill tool would be making its slow motion through the air, and much more time would be lost than would be the case with the quick return stroke of the planer. The reader will understand this more clearly if he will refer to Figure 70.

A flat annular surface, such as the flanged end of a valve, might be faced on a planer which has a stroke equal to the outside diameter and a side feed of the same amount. The cutting tool, in covering the square indicated at A, would machine the sur-

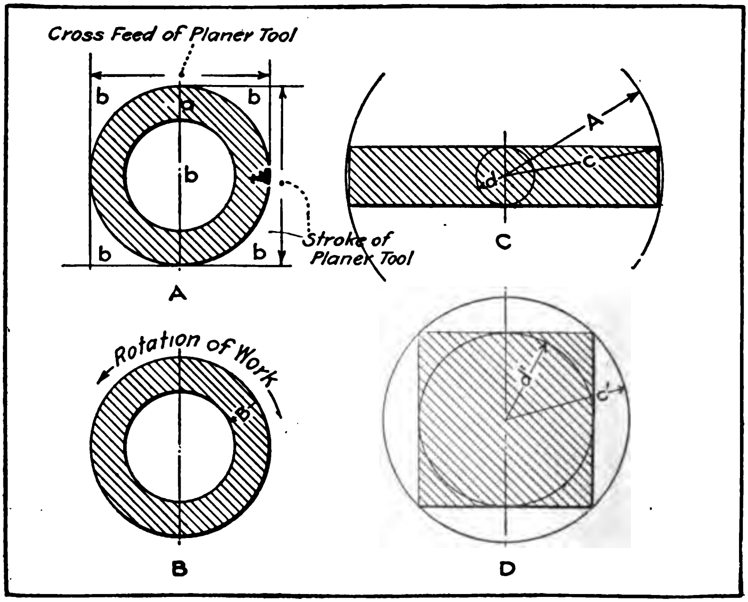


FIG. 70. EFFECTIVE CUTTING AREAS ON THE PLANER AND BORING MILL

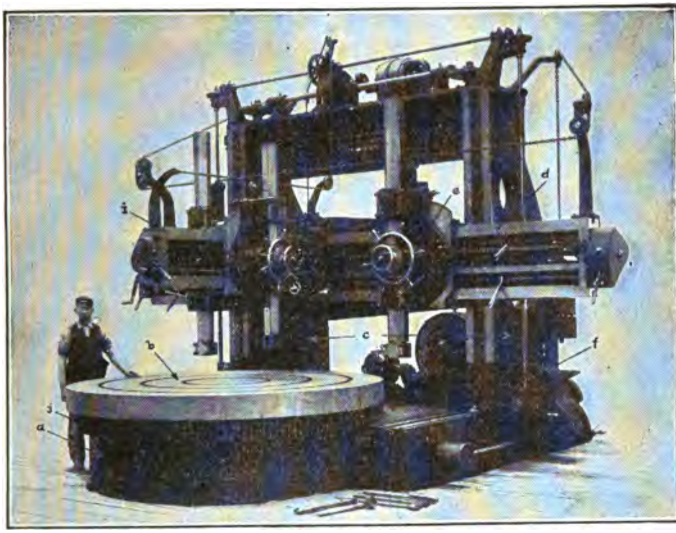
face, but it would do useful work only on the shaded portion, a. The motion of the tool over the unshaded portions, b, b, inside and out, represents lost time. If the job were done on a boring mill, the tool would be set at the outer edge, would be given an inward radial feed, represented by the width of the flange, and the work would be rotated under the tool, as indicated at B. In this case, the cutting tool would be in contact with the work all the time, instead of only part of the time, and the length of feed would be but a small fraction of that required in the first case. The advantage is therefore clearly with the boring mill.

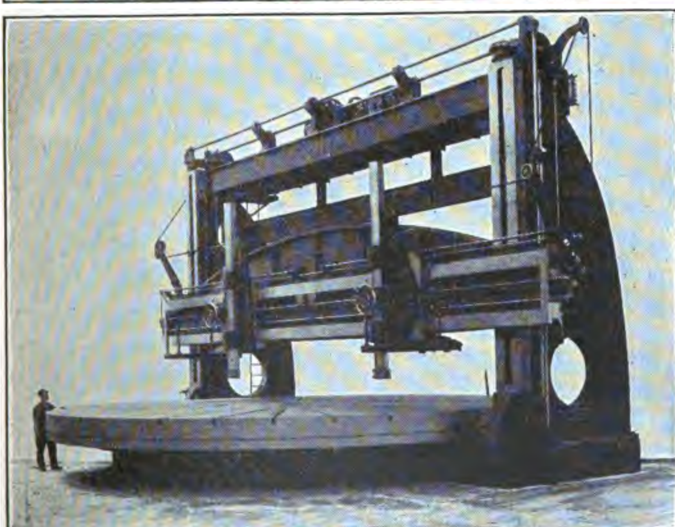
If, however, the face to be machined is long and narrow, as at C, the boring mill must take in a radius equal to the distance, c, across the corners, and the tool must be started at this radius and fed in to the center. Not until it has reached the radius, d, is the tool in the work during the entire rotation, and much time is therefore lost. If, on the other hand, the work is nearly square, as shown below at D, the proportion of time lost between the radii, c′ and d′, is much smaller, and the gain from having the tool in the work continuously inside the radius, d′, may render it desirable to do the work on a boring mill.

Construction of Vertical Boring Mill.—The tools in vertical boring mills are generally carried on a head which, in turn, is carried on a cross rail. This cross rail, in small mills, is mounted on a single vertical support, as in Figure 69, of box-like cross section, adapted to stand the combined bending and torsional

strains produced by the cut. In all except the smaller sizes there are two supports, as show in Figures 71 and 72. The single support, or upright, is used on machines that table up to about 42 inches in diameter. For medium-sized machines, ranging from this size up to 15 to 20 feet in diameter, there are two uprights rigidly bolted to the bed of the machine. For large mills, the two uprights are sometimes so arranged that they may be slid backward, as shown at f, Figure 71, away from the table, so that the diameter of work which may be machined is thus increased. Two, or even three, tool posts may be carried on the cross rail; and in small sizes, the tool head may be equipped with a turret and used in every way as the turret might be on a heavy turret chucking-lathe. Such a turret is shown at g in Figure 69. The heads, e, in all cases swivel about a center, may be adjusted to any angle, and have a power feed at the angle so set.

For straight boring or turning, the head remains stationary, and the tool post or turret, as the case may be, is fed vertically downward. For machining a taper surface, the head is set at the required angle and the tool post is fed in that direction. In this case, as in the previous one, the head would be clamped to the rail. When it is desired to machine a flange or flat face at right angles to the axis, the tool post is held in a constant position in the head, and the whole head is given a horizontal side feed along the rail. In certain types of the smaller boring mills, the upright is equipped with an auxiliary side head, h, shown in Figure 69, which has a vertical





FIGS. 71 AND 72. VERTICAL BORING MILLS

A 16-foot mill with adjustable uprights, above; a 34-foot mill, below. Both built by Niles-Bement-Pond Co.

feed up and down the face of the work and a horizontal feed toward the center. This head, also, may carry a turret tool holder, h′, and the tools may work simultaneously with those in the head carried on the cross rail. In this respect, again, the boring mill corresponds closely to the turret lathes referred to in Figures 56 and 57.

When two heads are carried on the cross rail, they are provided with independent feeds in all directions, in order that they may work simultaneously, and independently of each other. As the weight of the cross rail and heads is considerable, they are counterbalanced by weights, shown in Figure 71. In boring mills with the adjustable uprights, the latter are set well back, and the usual type of tool head, shown to the right in Figure 71, would not reach in close enough to the center to work on small diameters. This difficulty is met by mounting one of the tool heads on an extension, i, which reaches forward toward the center, enabling that head to machine the small diameters. The feeds of the cross rail on the uprights, the tool heads on the cross rail, the slides in the tool heads, as well as the feeds in the side head, if there are any, are all power-driven.

In the early history of the boring mill, although its great capacity for removing metal was clearly recognized, it was considered only as a roughing tool and accurate work was performed upon a large engine lathe. Of late years, however, the design and construction of the boring mill have been so refined and developed that it has almost completely taken over work of this character. This is

especially true in the case of the vertical turret machines, which have come into very wide use for such work in connection with car wheels, gears, and so on.

Table, Drive and Tools.—The revolving table in a boring mill is the important factor upon which accuracy and quality of the work depends. It should be very rigid, and capable of revolving smoothly at high speeds under heavy cuts. The spindle underneath, which corresponds to the spindle of the lathe, is a sufficient support for the smaller sizes. In all medium and larger sizes the spindle is relied on to do the centering only, and the weight and the vertical tool thrust are carried on a circular bearing of larger diameter, which usually is slightly conical so that it will be self-centering as it wears. The table is driven from a point near the rim, located as nearly under the cutting tool as possible to eliminate torsion on the spindle.

The bevel gear form of drive is most used, but it has some disadvantages, since it has a slight tendency to lift the table. To obviate this, worm gearing is used in some cases, as its action is smoother and more continuous than that of either spur or bevel gearing. For heavy work the worm gear is not available, on account of its low efficiency and heavy end pressure. Large boring mills are therefore driven by spur or bevel gearing; spur gearing is used on the largest types of machines, as shown at j in Figure 71.

The cutting tools used in these machines may be either of the type used on a heavy planer or of the

kind used in a large turret chucking lathe. The pilot bar principle, described in the last chapter, is made use of on the boring mill as well. The vertical boring mill, in its larger sizes, is used for work of a varied nature, ranging from general jobbing work to the machining of large castings incident to building heavy machinery of all kinds. The smaller sizes, with special tool equipment, are used for accurate repetition work on a strictly manufacturing basis. They are well adapted for this, since, because they require little floor space, the work may be set in position easily and quickly, and the machine will take heavy and simultaneous cuts with all the accuracy required in this type of work.

Bullard Mult-au-matic Vertical Lathe.—Figure 73 shows the Bullard Mult-au-matic vertical lathe, a development from the small boring mill shown in Figure 69. It is, in effect, five automatic chucking lathes arranged vertically around one bed, in a space 6 feet in diameter and 12 feet 3 inches high, including the motor. There are 5 tool heads, which will face, bore, and turn at any angle independently of one another; and 6 independently rotating chucks or tables, 14 inches in diameter, are carried on an indexing, circular base. Five of the chucks revolve under the tool heads—the sixth is at the loading position or station at rest. While a new piece is being set in this chuck, all of the others are working. When a new piece is in place, the circular base is indexed one station and each piece comes under the next tool head; the last comes to the loading station, finished and ready to be taken out. The next piece is then sent on its

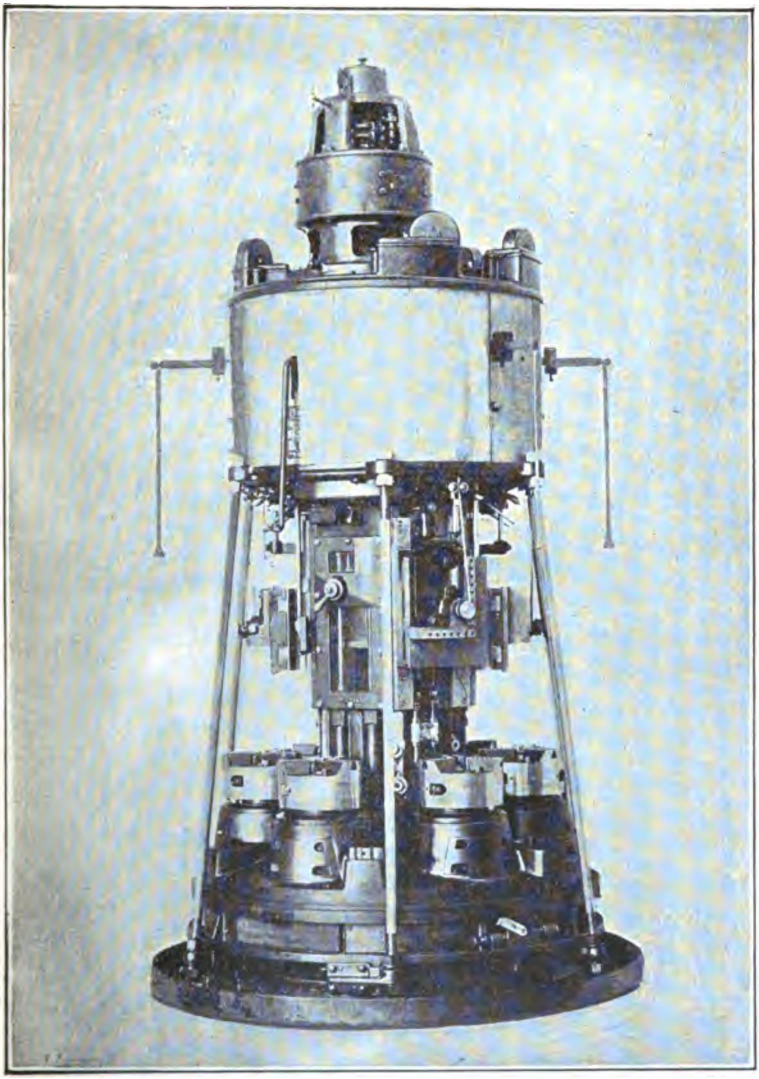


FIG. 73. "MULT-AU-MATIC" VERTICAL LATHE
Bullard Machine Tool Co.

way around. This method is an application of the "station" principle used in the multi-spindle lathes described in Chapter XIV. The indexing, fast and slow feeds of all the tool heads, both forward and return, are entirely automatic. This machine reduced the time of finishing a fly wheel on the Ford motor from thirty-two minutes to fifty seconds.

Horizontal Boring Machine.—As there is an analogy between the vertical boring mill and the lathe with the work bolted to the faceplate, so the horizontal boring machine may be likened to a lathe with the work bolted to the carriage. There is, however, a fundamental difference between these arrangements, since in one case the work revolves against the tool, and in the other the tool moves against the work. It will be found that there is a similar difference between the planer and the shaper. Which of these methods is the better, depends upon the size and shape of the piece, and of the cut in relation to the piece. The feasibility of revolving the work in an operation like that of turning a carwheel, is evident. It is equally clear that it would be disadvantageous to revolve a large engine bed around the center line of the main shaft bearing, merely to bore out that bearing. The swing required would be enormous and would call for a boring mill utterly disproportionate to the size of the cut to be made. With such a piece as this, it is obviously better to clamp the casting firmly on a base, place a boring bar on the center line of the shaft, and bore the bearing by revolving a tool carried by the bar.

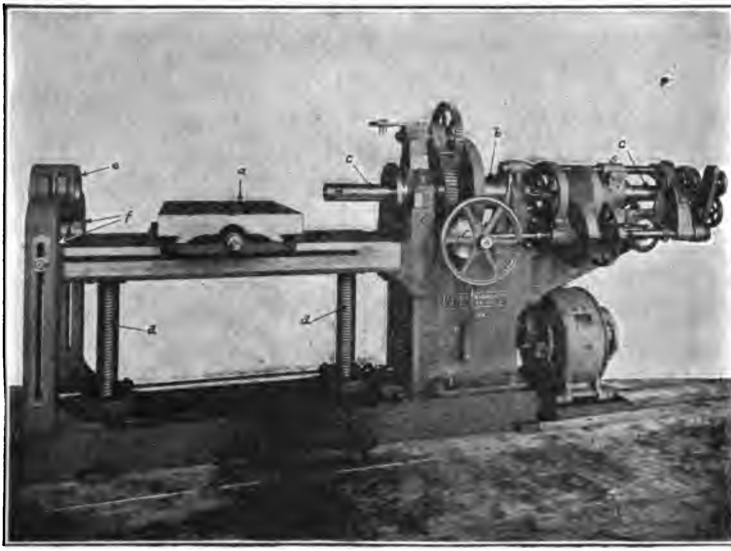
Unlike the vertical boring mill, the horizontal

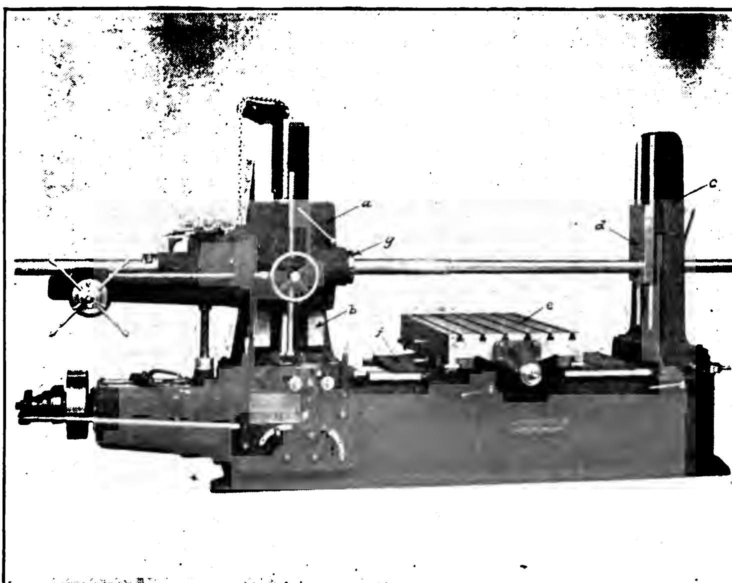
boring machine offers a means of machining conveniently and accurately surfaces which are related to several axes; these axes may be either parallel, at right angles, or even at an odd angle. A case in point is the machining of the main cylinder bore and the holes for the steam and exhaust valve in a Corliss engine cylinder. The latter holes—four in number—are parallel to one another, and at right angles to the main cylinder bore. The casting may be mounted on the table of a horizontal boring machine—like those in Figures 74 to 77—the cylinder hole bored, and the end flanges faced. The table, with the cylinder still clamped to it, may then be indexed through 90 degrees.

By operating the traverses of the table and the head spindle, the spindle may be brought opposite one of the valve holes, and that may be bored and its end flanges may be faced. The spindle center may then be shifted to coincide with each of the other three valve hole centers, and these may be finished successively as the first one was. All these operations may be finished, within the limits of accuracy of the adjustments of the machine, with a single clamping of the work upon the table. Thus it is possible to avoid the loss of time and the chances of error involved in shifting the work and making a series of set-ups. The horizontal type of machine is better for boring holes which are long in proportion to their diameter. This advantage comes from the use of the outboard bearing or tail-block which supports the boring bar at the farther end, as shown in Figure 75.

Similarity to the Lathe.—The horizontal type of machine is more closely similar, in general design, to the lathe than is the vertical boring mill. This is especially true of the machines which have stationary spindles and elevating tables, as in the Niles-Bement-Pond machine, Figure 74. The boring head is similar in position and general design to the headstock of the engine lathe, the essential difference being a provision for the horizontal feed of the spindle. This provision is usually made by having a hollow rotating spindle, b, without lateral motion, and an inner spindle, c, sliding longitudinally through this outer one, which is provided with an independent traverse feed. In machines of this type the table and platen, a, are carried on elevating screws, d, which afford a vertical adjustment for the adaptation of the table to various types of work. The outboard bearing, e, is carried in a stationary yoke, f, which corresponds to the tailstock of the engine lathe. This outboard bearing is used in boring long holes, or wherever support for the spindle is needed, and the yoke serves as a support to which the table may be clamped when it has been brought to the desired position.

An Adaptable Type.—Another widely used type is shown in Figure 75. In this machine, built by the Lucas Machine Tool Co., variation in height between spindle and table is obtained by adjusting the height of the boring head, a, instead of that of the table. The bed of the machine is of rectangular box section, and the boring head is carried on a heavy column at the left end of the machine; the head is adjustable vertically on suitable gibbed slideways, b. A stiff back





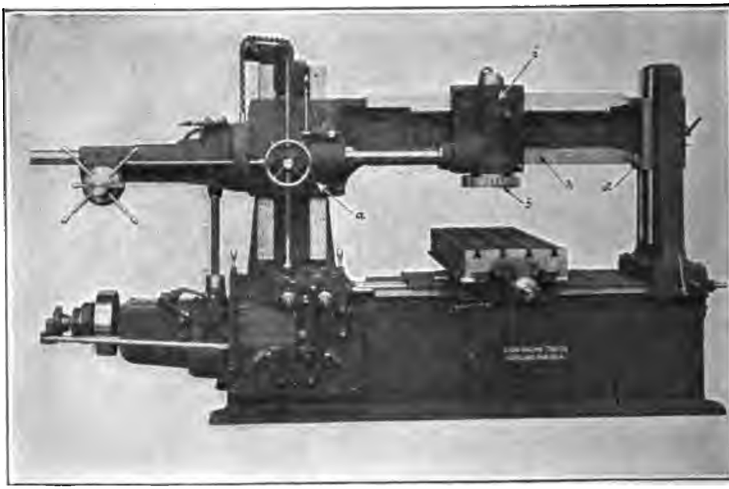
FIGS. 74 AND 75. HORIZONTAL BORING MACHINES

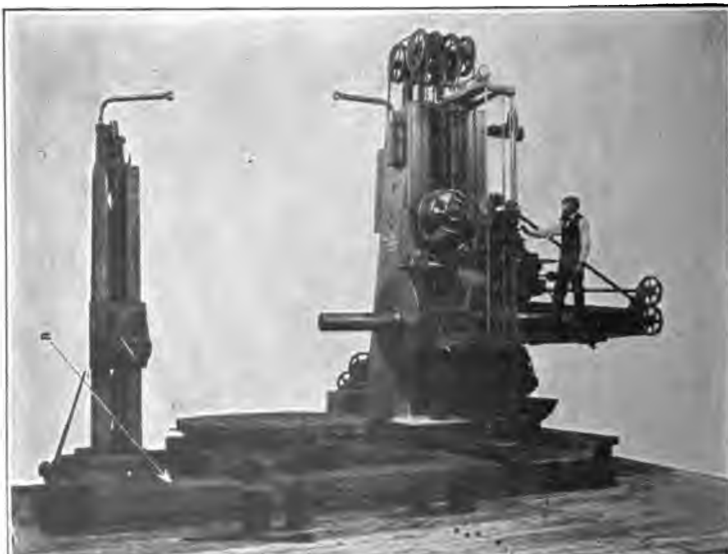
rest, c, at the right end of the machine has slideways for a tail-block, d, which is fed up and down in conjunction with the main boring head; the proper alignment with the spindle is maintained by feed screws operated through bevel gears from a common shaft. After the tail-block is in position, it may be locked in place, when it becomes practically of one piece with the back rest. The back rest, c, is adjustable forward and backward, so that it will accommodate work of various lengths, or it may be removed from the bed without disturbing any of the other mechanism. The main spindle is driven through back gears in the head, which are engaged and disengaged by convenient interlocking levers. The platen, e, is furnished with T-slots and with a circular swiveling table, not shown. It slides transversely on the saddle, f, which in turn slides lengthwise of the machine.

Power feeds are provided for the spindle in and out, the spindle and tail-block up and down, the saddle along the bed, and the platen across the saddle. Reverse feeds, rapid traverse, and hand adjustments are provided for all feeds. The machine has a constant-speed drive, which may be operated by either belt or motor, the variations in spindle speed being made through change gears operated by the levers at the front of the bed. This type of machine is useful for many kinds of boring, drilling, and milling operations. For drilling, the tool is mounted directly in the head spindle, g, and the platen is brought close to the spindle head. This position may also be used for milling operations; the milling cutter is mounted

on the end of the spindle or carried on an arbor between the head, a, and tail-block, d. For boring long holes, the tail-block and the back rest are used, the spindle is extended to run through the tail-block, and the cutting tool is mounted on the spindle, which is rotated and fed forward at the same time. For vertical milling work, an attachment is provided, which is shown in Figure 76. This consists of a heavy cast iron yoke, h, which spans the opening between the spindle head, a, and the tailblock, d, and is firmly bolted to each. On this yoke is mounted a traveling head, i, carrying a vertical spindle driven from the main spindle through bevel gears. A face milling cutter, j, may be mounted on the lower end of this spindle, and the machine may be used to do vertical milling operations. In the latest type of Bement boring machine, all the operating levers are arranged in pairs, one on each side of the machine, so that it may be controlled from whichever side happens to be most convenient. Figure 77 shows a much larger machine of the same general type.

Portable Boring Machines.—In very heavy machinery—as, for instance, rolling mill engines—some of the parts to be machined are of very great size and weight. In machining such pieces, it would be expensive and inconvenient to shift their positions to make the various cuts required. It is simpler and easier to move the machines around the castings. Shops equipped for work of this magnitude are provided with slotted floor plates, which are located in the main bay of a building of the type shown in Figure 1, under the large traveling crane.





FIGS. 76 AND 77. HORIZONTAL BORING MACHINES

The upper, Fig. 76, is shown with vertical milling attachment, and is built by Lucas Machine Tool Co. The lower machine is built by Niles-Bement-Pond Co.

These plates are built up of sections, and may cover a considerable portion of the floor. Their upper surface is machined and is provided with T-slots. They are firmly bedded in a heavy concrete foundation and, when finished, correspond, except for their much greater size, to the base plate, a, shown in Figure 77. The large casting to be machined is brought in from the foundry, leveled, and clamped in place upon this floor plate; it is not moved until all the machine work is done. When boring operations are necessary, a portable boring mill—corresponding to the vertical portion of the mill shown in Figure 77—is placed in position on the floor plate beside the casting, is clamped into place, and the operations called for at that location are performed.

When it is necessary to move the machine to some other part of the casting, the crane hook is slipped into a heavy loop, or bail, at the top of the machine, and it is lifted bodily, turned around, and transported as may be necessary. It is set in its new location, and the slots in the floor plate are used to orient the machine in proper position. The same thing is done with other types of machines, such as large draw-cut shapers, and so on. Whether it is desirable to move the machine around the work or the work around the machine, is largely a question of the relative size of the two; when the work is of very great size, the former method is the cheaper. Portable boring machines of this type are invariably motor-driven, the motor being mounted on the machine itself and transported with it.

CHAPTER XVI

DRILLING MACHINERY

The Sensitive Drill.—Drilling machines, in some form, are found in every shop. They are used for drilling round holes in all kinds of castings and forgings; for tapping or threading the holes; for countersinking or making a tapered enlargement of the upper end of a hole; for counterboring or making an annular enlargement of the upper end of a hole; for reaming, which is passing a reamer through the hole to increase the accuracy of form; and for spot facing, which is making a shallow counterbore deep enough to form a smooth face for the head or nut of a bolt.

The smallest and simplest form is a sensitive drill, Figure 78. It consists of an upright standard, a smooth horizontal table on which to rest the work, a vertical spindle capable of holding and rotating the drill, and means for feeding either the work or the drill, usually the latter. The variations in speed are generally obtained by means of friction disks which form part of the driving mechanism. One of these disks, a, revolves in the vertical plane parallel with the axis. A horizontal driving wheel, b, on the spindle has a narrow leather band, c, which bears against this. The leather-faced wheel is adjustable vertically and, when set to bear upon the vertical

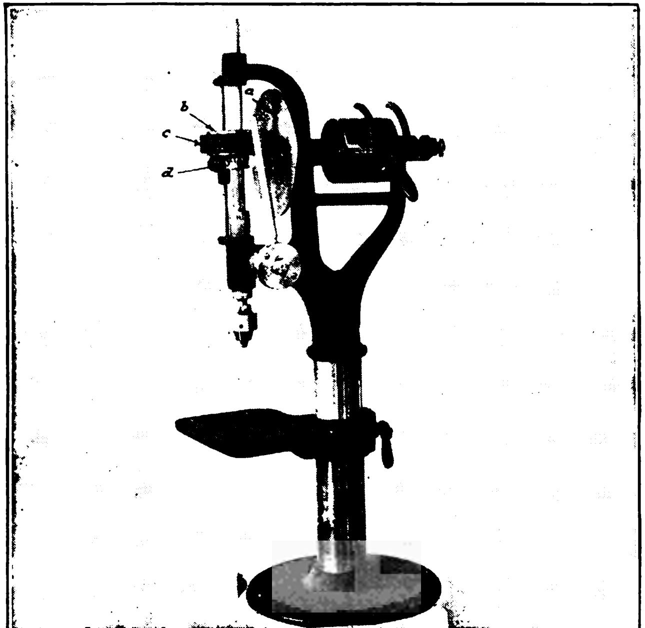


FIG. 78. SENSITIVE DRILL

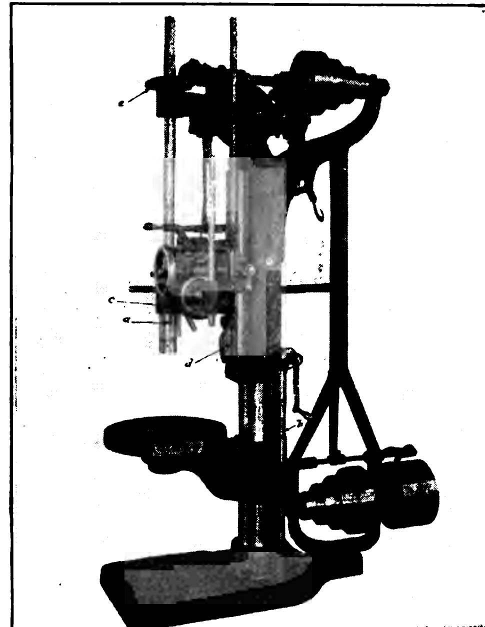


FIG. 79. STANDARD UPRIGHT DRILL PRESS
W. F. & John Barnes Co.

disk near its rim, will drive the spindle at the greatest speed. By lowering it toward the center of the vertical wheel, the speed may be reduced to zero. By lowering it still further, the direction of rotation may be reversed. The wheel, b, drives the spindle by means of a sliding key, or spline, and is retained in its proper position by the finger, d, while the spindle is fed downward by means of the light hand-lever shown at the right. In some types, the friction disks are arranged at the base of the upright, and in others the variations in speed are obtained by means of cone pulleys. The drill is often used as a bench machine, and only for light rapid work of the simplest nature.

Upright Drills.—The commonest type of drill is the standard upright drill press, shown in Figure 79. The essential elements are the main upright or column, the table, the spindle, and the driving and feed mechanism. The drill, or tool, is carried in a smooth tapered socket at the lower end of the main spindle, into which it will seat itself firmly enough to transmit the power required to make the cut. To remove it, a taper key or drift is inserted through the slot, a, and driven across the end of the shank of the drill, which forces it out of the hole.

In most upright drills the lower portion of the column is cylindrical, as shown, and the table is carried on a swinging arm, which is capable of being raised or lowered by means of an elevating screw, b, shown at the right, and clamped to accommodate different types of work. The circular table is carried at the end of this arm on a short vertical spindle, the

center of which is at the same distance from the frame as the drill spindle. This arrangement of swinging arm and rotatable table is very convenient in the drilling of bolt holes in flanges. A flange may be clamped concentrically to the table, and the center of the table set off to one side a distance equal to the radius of the bolt circle. The table may then be rotated about its center and the successive holes drilled in turn. In most upright drills the column branches out at the top, one branch curving forward to carry the upper bearing of the spindle and its driving mechanism, the other branch curving backward to carry the bearing behind the upper driving pulley.

Details of the Drive.—The chief strain to which the column is subjected is the upward axial pressure against the drill, which produces a bending movement. In many drills this is cared for by the addition of a secondary column in the rear, which helps to carry this strain. The lower end of the driving spindle is carried in the sliding head, c, which is gibbed to a vertical slide, on the front and upper portion of the column. The spindle, like that of the horizontal boring machine, has two motions—one of rotation, and the other of longitudinal traverse. It consists of a vertical steel shaft passing through two sleeves. The upper one, driven by the bevel gear, e, imparts the rotary motion to the spindle through a sliding key; the lower sleeve slides vertically without rotation, carrying the spindle up and down, and is actuated by a rack-and-pinion feeding mechanism located in the head. The upward thrust in most

modern drills is cared for by ball or roller thrust bearings, which are clearly seen in the heavier machines, shown in Figures 80 and 81.

In many machines the lower head, c, Figure 79, is cast solid with the column; this arrangement gives a stiffer construction. The sliding head, however, with its adjustment up and down, is more convenient for varying heights of work, gives a longer vertical movement to the spindle, and supports it close to the drill at all times. In some machines the sliding head itself moves up and down with the feed; in others the head is clamped and the spindle is fed downward through it. The latter form is a little more rigid, while the former does away with the rack and pinion on the sleeve, and permits of a longer traverse. In addition to the adjustable swinging table, most upright drills are provided with a forward extension of the base which is planed and slotted to hold large work.

The driving mechanism consists of a countershaft with a tight and a loose pulley, and a cone pulley usually located at the base of the machine, as shown. The upper shaft carries the secondary cone and the necessary gearing for the speed changes. The front end of the shaft carries the bevel pinion which drives the bevel gear, e, and through it the main spindle. All except small drills are provided with power feed, and most of them are, or may be, equipped with tapping attachments used for threading holes. The various adjustments may be operated by hand as well as by power.

Heavy Duty Drill-Presses.—While the circular column is very convenient in many ways, it is obviously

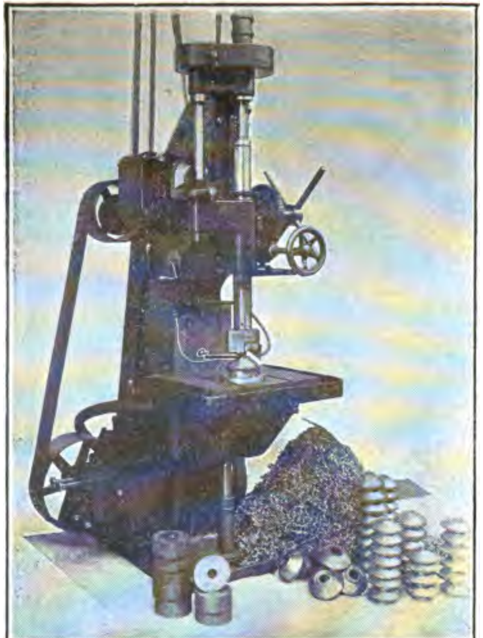


FIG. 80. HEAVY DRILL PRESS FORMING BEVEL GEARS

FIG. 81. EXTRA HEAVY DRILLING MACHINE; SPINDLE END OF 10-INCH DIAMETER AT BOTTOM
Baker Bros.

limited in strength. Heavy-duty drill presses for large work and for use with high-speed steel may take the form shown in Figures 80 and 81; the frame is a heavy box section designed for severe service, and the upper and lower spindle bearings are both solid with it.

The machine shown in Figure 80 has a single-speed belt drive; the main driving pulley, being on the other side of the machine, is not shown. The axis of the driving pulley is parallel to the front of the machine, an arrangement which allows the machine to be set as one of a row down the shop. The speed changes are provided through change gears. The feed mechanism is very powerful, and is provided with a safety device to protect the driving mechanism in case of overload. This device takes the form of a "shearing pin" proportioned to let go when an overload is reached. The swinging table is done away with, and an adjustable table mounted on heavy guides is substituted, as in Figure 80. For the still heavier machines, shown in Figure 81, the work is carried on the slotted floor plate. The plane surfaces at the front of the uprights on the latter machines are employed, not to carry work, but to support guides (not shown), which may be used to steady the spindle when desired.

This type of machine is similar in many ways to a horizontal boring machine, except for its vertical position, and is used for many kinds of boring operations. Figure 80 shows a set of tools in place for doing a typical boring operation—the turning of the conical face of bevel-gear blanks. This is a case of what is

known as "second operation" work. The blanks in the smaller pile at the left show that a hole has already been drilled and one side has been faced. The tool head is equipped with a pilot bar, a, which enters this hole and centers the spindles during the heavy cutting operations, which here include facing the top, turning the hub, and facing the conical surface. The machines shown in Figure 81 are heavy enough to do much of the work that used to be done on a boring mill, for the spindle is 10 inches in diameter at the end. The one in the foreground is fitted with heavy facing tool and pilot bar. While technically known as drilling machines, these have really passed into the boring-machine class.

Radial Drills.—As the work grows larger, it is easier to move the tool about the work than to shift the work under the tool. A class of drilling machines, known as radial drills, have been developed for this service. These are known as plain, half-universal, or full-universal drills according to the character of the motion that may be given to the drilling head. In the plain radial, shown in Figure 82, the drilling head, a, has a motion in and out from the column, and may be swung radially about the column, its axis at all times remaining vertical. In the half-universal, the head swivels in a vertical plane parallel to the face of the arm, so that the spindle may be set at any angle in that plane. In the full-universal, the radial arm itself has a swiveling motion in addition. Such a machine is shown in Figure 84. It is remarkably flexible, and will drill a hole at any angle.

The plain radial is simpler, easier to operate and, because it has fewer joints, is more accurate, but it is of course more limited with respect to the work that it will do. The base of the radial drill has a heavy floor plate under the arm for carrying the work. These are often fitted with a removable slotted table, or block, as shown, to accommodate lighter work; if the squared surfaces are used, holes may be drilled at right angles. Some radials are fitted with blocks which may be tilted on bearings, and which carry a round swiveling plate. This attachment gives to the plain radial the flexibility of a full-universal, but such a holding device will not handle as large work as a full-universal drill.

The Column and Driving Mechanism.—Of the several types of columns the favorite is the double circular—a section is shown in Figure 83. The inner column, a, is part of the fixed frame of the machine. It has a circular ball bearing, b, at the top, and a large sliding bearing, c, at the bottom, which carry the outer sleeve, d. The downward thrust of the weight is carried on the ball bearing, e. The large bearing, c, at the lower end of the outer sleeve, d, is split, and is provided with a clamp operated by the handle, b (Figures 82 and 84), which binds the surfaces together, and clamps the outer sleeve and arm in any position desired.

The radial arm slides on the smooth cylindrical surface of the exterior column, or sleeve, and is provided with an elevating screw, c, shown in Figure 82, to raise and lower it. When the desired height is reached, the operating screw is thrown out of gear

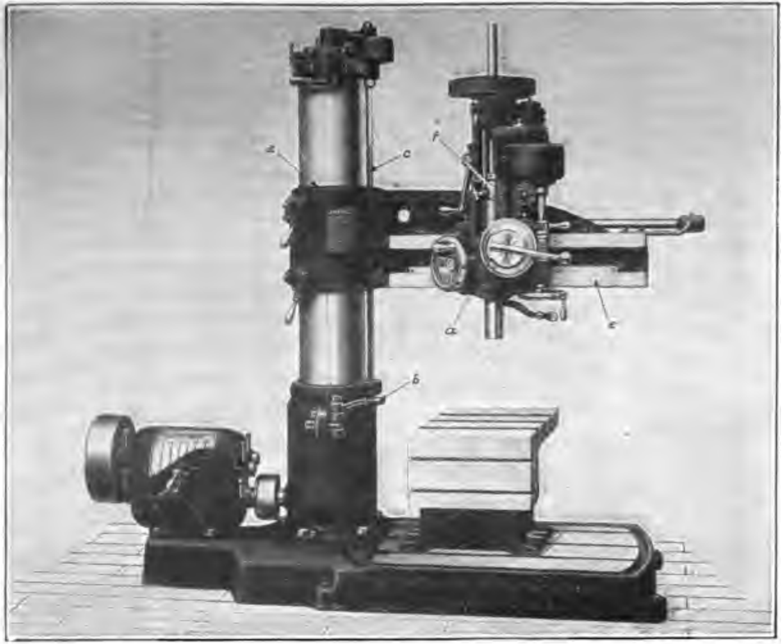


FIG. 82. THREE-FOOT PLAIN RADIAL DRILL WITH SEPARATE BOX TABLE
American Tool Works Co.

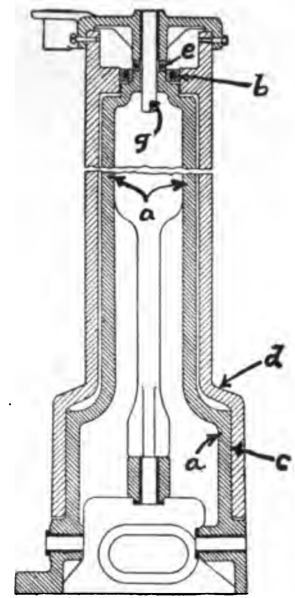


FIG. 83. SECTION OF RADIAL DRILL COLUMN

and the arm is clamped to the sleeve by means of the handles shown at the left. When the arm is thus clamped to the sleeve, it becomes practically solid with it. All the rotary motion takes place in the bearings, b and c (Figure 83), at the top and bottom of the column, while the vertical motion is cared for solely by the joint, d (Figures 82 and 84), between the outer sleeve and arm. The radial arm is designed to carry the heavy vertical thrust of the tool.

On the side are slideways, e, which carry the drill head. This head contains the mechanisms for revolving the spindle at the proper speed for the power feed of the drill, for stopping them, and for the quick return. The spindle, as in other drills, has a rotary and a vertical motion. The spindle is graduated at f, so that the depth of the hole may be known, and some machines are arranged with a device that may be set to disengage the feed at any depth desired.

The machine is driven by a single-speed pulley through a change gear box at the base of the column, thence through a pair of beveled gears upward through a shaft, g, concentric with the column, to gears located on the top. From these the power is transmitted downward, outside, to the radial arm, and outward to the mechanism located in the head. All of the power feeds are also equipped with hand control mechanisms. In some drills there is a floor plate on each side of the column, so that the work may be set up on one side while drilling operations are going on at the other side, and often the table is at the side, as at h in Figure 84. In the full-univer-

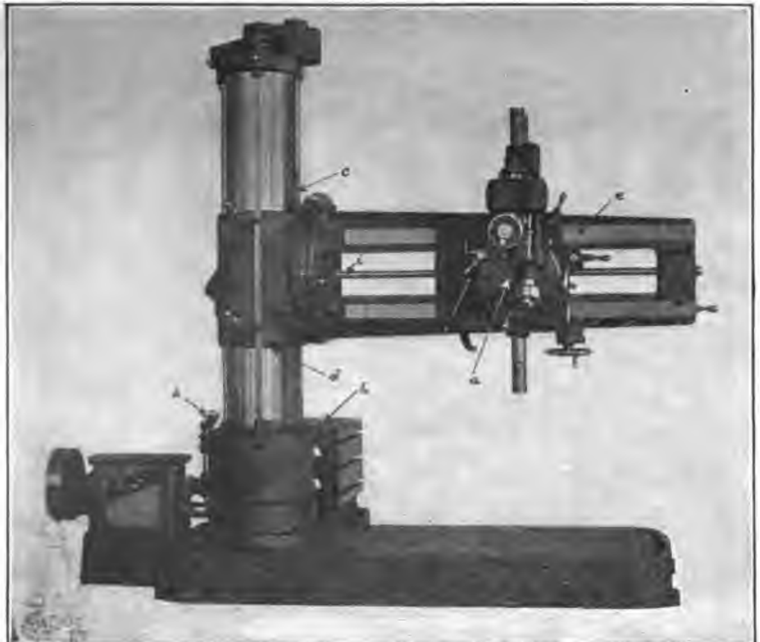


FIG. 84. FULL UNIVERSAL RADIAL DRILL
Showing speed box drive, plain table, and standard base, built by the Cincinnati-Bickford Tool Co.

FIG. 85. MULTIPLE SPINDLE DRILL
Pratt & Whitney Co.

sal the driving motion is carried from the motor to the drill through shafts located in the axis of the swiveling joints, where the arm turns on its supporting piece and the spindle head turns on the saddle. One of these, i, is clearly shown in Figure 84, coming out centrally along the arm. The spindle at the center of the head, a, which the shaft, i, drives, is hidden in the head.

Multiple-Spindle Drill.—Many classes of work call for the drilling of a number of parallel holes, as, for instance, the bolt holes in a flange. The multiple-spindle drill has been developed to drill such holes simultaneously. In this type, one of which is shown in Figure 85, the frame is a box-like column with an adjustable sliding table. Instead of the single spindle with its drill socket there are a number of drill sockets, a,a, carried in adjustable brackets, b,b, mounted on the basket-like head at the top of the machine. Each of these short spindles, with its socket, is adjustable in and out and sidewise, and is driven by a double-universal joint, c, from a corresponding fixed upper shaft, c′; the lower ends of some of these may be seen through the opening in the head.

These upper shafts are fixed in position and arranged in a circle around a common driving pinion operated from the large horizontal pulley on the top of the machine. This pulley is driven by the half-turn belt, which extends back, horizontally, over the guide pulleys and down to the main driving pulley below. When this pulley is rotated, it drives all of the spindles at the same speed. Any number of the

spindles, from one to the full number, may be employed as desired; those not used are pushed off to one side out of the way.

When, for instance, it is desired to drill an eight-holed flange, eight of the spindles are arranged in a circle at the desired radius, the drills are inserted, and all the holes are drilled at the same time. In the machine shown, the work is lifted against the drills, as this arrangement somewhat simplifies the problem of driving. To permit this, the front of the machine carries a saddle, d, which is adjusted to the height desired. This saddle, d, in turn carries a slide, e, which is operated by a rack and pinion through the hand lever, f. The table, g, is bolted to the slide, e, and moves up with the work as the lever is pushed down; stops are provided to limit the motion when desired. Other makers keep the table still, and bring the head with all the drill spindles down toward the work.

For certain classes of work, such as the drilling of the holes in the flanges of cast-iron pipe, the machine is arranged in a horizontal position on a long bed, somewhat like a lathe bed, and two drilling heads, similar to the one shown, are arranged one at each end. Each of these heads carries a set of drilling spindles, and may be fed inward toward the center, drilling all of the holes in both ends at the same time.

Drilling Jigs.—Drilling is not a very accurate operation, as there is a heavy reaction against the end of the drill which tends always to force it out of line, if conditions are not absolutely right. Further-

more, the spindle frequently projects some distance from the bearings and the drill projects from the end of the spindle, conditions increasing the tendency to spring, or "run." In manufacturing practice, this tendency is reduced and the accuracy of the drilling process is greatly increased by the use of drilling jigs. These may vary from a simple template, with bushings in it, to complicated and ingenious devices.* The function of the jig is to clamp the work firmly in position, and to hold in the correct location a hardened steel bushing the size of the hole to be drilled.

This bushing is usually located in a leaf, which is turned down into position after the work is in place. The hole in the bushing is rounded at the upper end in order that the end of the drill may find its way easily into the hole; the bushing should be set as close as possible to the surface to be drilled. As the bushing is hardened, the drill makes no impression upon it, and the former acts as a guide to hold the drill in the exact location desired. More than one hole may be drilled in the jig, and these holes do not necessarily have to be of the same size. Practically all repetition work is drilled with the use of jigs, and these may often be very elaborate. The Ford motor cylinder base is drilled, in one of the operations, in a jig in a special machine that has forty-five drills operating simultaneously from four sides.

When a single hole is to be drilled in an ordinary drill press, a prick punch mark is made on the center of the hole, and a circle is scribed around it the size

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* For a detailed description of drilling jigs see "Tools and Patterns," by Albert A. Dowd, Vol. 4, Factory Management Course.

of the hole. The hole is just started with the conical nose of the twist drill, and the drill is then withdrawn. If it is found that the hole has started eccentrically, part of the material is chipped away on the side toward the center and the drill is brought down to the work again. As there the material is then less on the side toward the center, it tends to run over toward that side and to correct the eccentricity. This process is repeated until the hole is started true. This is skilled work and takes time—it is evident why the use of drilling jigs, which obviate this difficulty, is so general.

Work Commonly Done on Drill Press.—For very accurate deep-hole drilling the relative rotation of the work and the drill is reversed; the drill is held stationary and the work is revolved. This arrangement is less convenient, but gives a more accurate result, and is the method used in drilling the long accurate holes required in gun manufacture. At the beginning of this chapter a number of operations were mentioned, which are done on a drilling press in addition to ordinary drilling. Countersinking and counterboring are second operations which would naturally be done on a drill at the same time the hole is originally made. In these operations usually a pilot bar is employed which enters the hole and centers the cutting tool that does the enlarging. Reaming is another second operation which naturally is done on a drill press. For accurate work, the reaming tool is connected loosely with the driving spindle, so that the spindle merely rotates it, and in no way controls its position. Thus the reamer is

allowed to find its own center and do true work. Tapping is one of the commonest operations performed on the drill press, and most drills are provided with attachments for this work. In most cases the connection between the tap and the driving spindle is made through some form of friction drive which transmits enough power to make the normal cut. If, through carelessness or otherwise, the tap bottoms in the hole, the friction drive slips and prevents the breaking of the tap.

Heavy-duty drills are used for many operations that might be classed as boring work. By the use of pilot bars and self-contained guiding devices in fixtures especially designed for the purpose, accurate work may be done on drill presses to great advantage, and they are increasingly used for this class of work.

CHAPTER XVII

PLANERS, SHAPERS, AND SLOTTERS

Definition of Field.—Flat surfaces may be finished with a reciprocating cutting tool in a planer, shaper, or slotting machine. While the fields of these machines overlap somewhat they are, in the main, fairly well defined. The planer is used for long and narrow faces, and for machining a number of pieces that may be set up one behind the other, making, in effect, one long surface. It is also used for surfaces that are straight in one direction, but not necessarily flat. One good example is the top of a lathe bed, Figure 47, in which the flat faces and V-ways may be finished at one setting. The inside surface of the upright guides in a drop hammer, shown in Figure 22, is another example. Generally speaking, the planer is used for large cuts on heavy pieces. The feeding motion is given to the tool, and the cutting stroke is made by moving the work past the tool.

The shaper is very convenient for special cuts on small work, and is therefore especially suited to the class of work done in the tool room. In the standard type of shaper, the cutting motion is given to the table and nearly all of the feeds are given to the table carrying the work; the only feed given to the tool is a hand feed downward. The slotting machine is used

on medium- and large-sized work, for edging cuts, inside faces, and keyways that are to be at right angles to some face which, usually, has been machined in a previous operation. In the slotter, as in the shaper, the working motion is given to the cutting tool, and the feed is taken by the table carrying the work. The stroke of the cutting tool in the shaper is horizontal, and in the slotting machine it is vertical.

Early Types of Planers.—The first planer of anything like modern design, of which we have record, was built by Richard Roberts in England in 1817. The machine is now in the South Kensington Museum in London. Chisel and file marks on the bed and ways indicate that it was itself made without the use of a planer. The machine was small—it took in work less than a foot wide; the table was operated by hand by means of a chain drive. Within twenty years, Joseph Clement built a planer that would take in work six feet square; it was for many years known as "The Great Planer." Work was brought to it from all the districts about London, and it is said to have earned for its owner $100 a day for many years. This, by the way, was also a hand-operated machine.

The Modern Planer.—Today the planer is found in all shops that do medium- and large-sized work. It uses the standard type of single-edged cutting tool, and the tool equipment, unlike that of the milling machine, is inexpensive and may be used for a great many purposes. A disadvantage of the planer, as well as of other machines with a reciprocating action,

is that it has an idle return stroke. In the early forms of planer the motion was derived from an ordinary crank, and the return stroke was made at the same speed as that of the working stroke. The slow return stroke has long since been eliminated by the use of some form of driving mechanism that quickens the return, and so cuts down the idle time. It would seem comparatively easy to make a planer that would cut both ways—many have been tried. For a number of very practical reasons, however, they have never been successful.

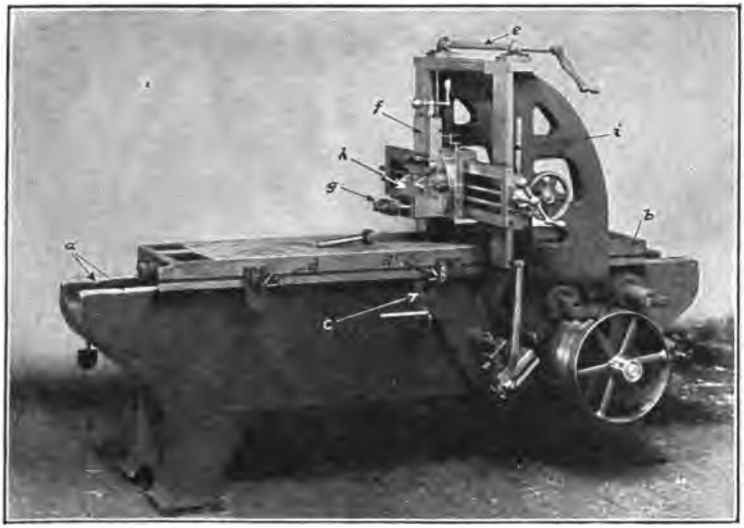
The flexibility of the planer, and its adaptability to various uses, require a skilled mechanic to run it. This principle is general throughout the whole field of machine tools. Adaptability in a machine tool requires a number of feeds and adjustments that call for skill in setting. When a tool becomes a single-purpose machine, the adjustments may be simplified and reduced in number so that a comparatively unskilled attendant may operate it.

Standard Type of Planer.—The standard type of planer is shown in Figure 86. It consists of a deep, heavy bed which has accurately machined slideways along the entire length of the top. A heavy platen, which carries the work to be machined, slides on these ways. The bed is hollow and rectangular in cross-section, is heavily ribbed, and carries the bearings, and so on, for the mechanism that operates the traverse of the bed. The platen must be long enough to carry the longest piece that the planer will have to handle, and the bed must be long enough to carry the platen and to permit it a travel equal to the

longest cut to be made. The length of the bed is, therefore, a little less than the length of the platen, plus that of the longest cut. Accordingly there are about 20 inches of length of bed for each foot in the length of the platen.

The slideways on both bed and platen must be true, since upon their correctness depends the accuracy of the work. They should be liberal in area, and should provide means for the take-up of wear. In American practice, this is usually done by making at least one of the ways of V-section. In the smaller ma-machines, both of the ways, a,a, may be of this section, as in Figure 86 and 87. But when the platen has considerable width, one of them is a plain flat surface, and its only function is to give a vertical support to the platen; the other is relied on to guide the platen in a horizontal plane. The heavy planer shown in Figure 90 has three ways—a V-way in the middle, and a flat one on each side. The top of the platen is provided with T-slots and holes, which aid in clamping down the work. On the under side of the platen is a rack, which is driven either by a gear wheel or by an endless screw. The platen has no motion other than that of reciprocation along the ways on the bed. All the feeding motions are given to the cutting tool.

Rack-and-Pinion Drive.—With the rack-and-pinion drive, the power is usually transmitted to the table through a train of gears housed in the bed from tight and loose pulleys at the side of the machine, which are clearly shown at b, Figure 86. Open and crossed belts are used on these pulleys, one for the forward cutting motion and the other for the quick return



FIGS. 86 AND 87. STANDARD PLANERS
The 20 x 17-inch type, above, is made by Whitcomb-Blaisdell Machine Tool Co. The lower view shows a 42-inch Niles-Bement-Pond planer.

motion. They are driven from a countershaft above, and are shifted backward and forward from the tight pulleys to the loose pulley. Various forms of shifting mechanism have been developed by the different tool-builders for this purpose. The motion required is not so simple as it might seem, for two belts can not be on the loose pulley at the same time; hence, one must be shifted somewhat ahead of the other.

The shifting of the belts, with the resulting reversal of the motion of the platen, or table, is controlled from a tripping device located at the side of the bed. This usually takes the form of a lever, c, which may be thrown by hand when desired, but which, in the ordinary operation of the machine, is thrown by two adjustable stops, d,d′, located on the side of the platen. These may be moved along the side and clamped in any position required. The stop, d, at the front end of the platen, strikes the lever, c, at the end of the cutting stroke, throws out the main forward drive, and throws in the quick return. When the plate has traveled forward to the point desired, the stop, d′, reverses the drive and throws out the return motion, and the next cutting stroke begins. With the stops in the position shown, the platen will make a comparatively short stroke near the middle of its possible travel. If the stops were both well forward to the left, the bed would make a short stroke with the front end of the table under the tool; with the stop, d, at the front end, and d′ well to the rear, the platen would make a full stroke and the tool would make a cut for the entire length of the capacity of the machine.

The Uprights.—Either cast solid or bolted firmly to the sides of the bed, are the two uprights that carry the cross rail and the tool heads. These uprights are usually two in number, one on each side, and the tables passes between them. The bracing of the uprights is usually parabolic in form—as in Figures 86 to 88—the correct design for maximum strength to withstand the main thrust of the tool as the work comes forward on the cutting stroke. The brace across the top helps the uprights to withstand the side pressure, which is also present, and which may be very considerable.

On the front of the uprights are machined slide-

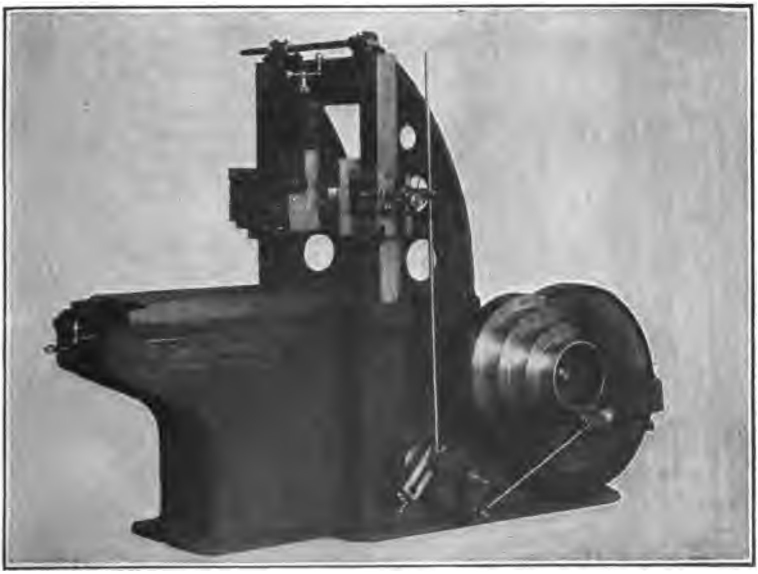


FIG. 88. 24 BY 24 BY 24-INCH CRANK PLANER
Cincinnati Shaper Co.

ways, to which the cross rail is gibbed; elevating feed screws in the slideways operate the two ends of the cross rail up and down. The elevating screws are connected across by a common operating shaft, e, to operate in unison and insure parallelism in the motion of the two ends of the rail. On the rail are mounted one or more saddles, which carry the tool heads.

In small planers there will be one of these heads, as shown in Figures 86 and 88, but on all medium- and large-sized planers there are two heads. When there are two heads, the cross rail is made long enough to allow the full motion across the platen of either head. The tool head, in all cases, has a sliding member, f, which has a cross feed, and which carries a tool-holder. This head, with its feeding screw, may be indexed at any angle, and the cutting tool may be fed downward on that angle when desired. The cutting tool is carried by a clamp, g, shown on a leaf, or clapper, h, which is pivoted at its upper end. The purpose of the pivot is to allow the tool to lift clear of the work and to ride upon it during the return stroke. When the work has run past the tool on the return stroke, the leaf with the cutting tool drops back into place and is ready for the next cut.

Feed Motions.—On all planers of any considerable size, the various feed motions are power-driven as well as hand-operated. These motions are as follows: First, a downward feed of the cutting tool in the head, which as said before, may be set to operate at an odd angle; second, each of the heads has an independent traverse feed along the cross rail; and, third,

the cross rail as a whole has a feed up and down on the uprights. The various power feeds are arranged to take place at the beginning of the return stroke, and the tool is stationary during the working stroke. The mechanism controlling these feeds is operated from the vertical rack, i, on the outside of the right-hand upright.

Since the axes of most of the shafts in the main drive are at right angles to the motion of the table, the driving pulleys are generally arranged at right angles to the machine, as shown in Figure 86. This plan usually necessitates setting the length of the planer across the shop, in order to place the driving pulleys parallel to the line shafting, a position which may be inconvenient and obstruct the floor. To avoid this the axis of the driving pulleys may be set parallel to the machine, as shown in Figure 87, an arrangement which permits long planer beds to be placed lengthwise of the shop.

The spiral-gear drive, introduced by William Sellers, of Philadelphia, does away with most of the reducing gears necessary in a spur-gear drive. The rack underneath the platen is operated by a worm, or "endless screw," carried on the end of a shaft; this shaft extends outward at an angle to the side of the main bed, where it is driven by bevel gears from pulleys, which may stand either at right angles or parallel to the bed. It is used on the larger sizes of planers, and has the advantage of great strength, simplicity, and smoothness of action.

In recent years, belts have been done away with entirely on many planers and the machine is driven

by a reversing electric motor directly coupled to the driving shaft in the bed of the planer, as in Figure 89. The reciprocation of the table is accomplished by a reversal of the current in the motor, controlled by stops on the side of the bed similar to those described in connection with Figure 86.

Special Types of Planers.—Small planers may be operated by a Whitworth quick-return motion similar to that shown in Figure 96. These are known as crank planers. The stroke is rapid and smooth in action, and may be varied in length and position as in the case of the belt-driven planer. This type of planer is always of comparatively short stroke. The one shown in Figure 88 has a stroke of 24 inches.

Figure 89 shows a modification of the standard type of planer, known as the open-side planer. One of the housings is eliminated and the cross-rail is carried on a heavy extension arm or knee that reaches across the table from a heavy upright. The upright has a box section capable of withstanding the torsion produced by the pressure on the tool. The ordinary type of planer is limited to work that can pass between the uprights. In this type, work may be clamped on the table, which extends over to one side, and the machine is therefore capable of planing work that is wider than the table. Large planers, of both the standard and the open-side type, may be equipped with tool heads on the uprights as well as on the cross rails, for machining the sides of a casting while the rail heads are working on the top. One of these side heads is shown in Figure 89. Open-side planers are sometimes provided with an auxiliary

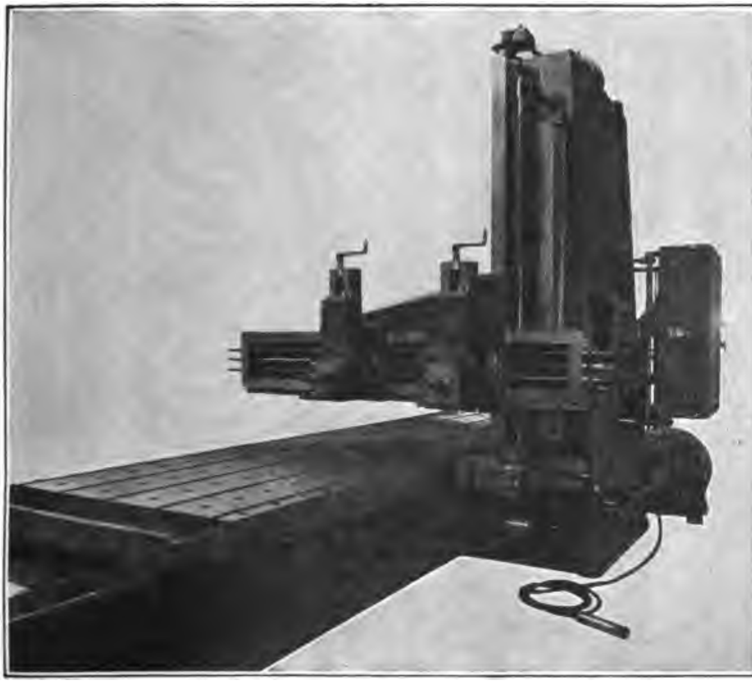


FIG. 89. OPEN SIDE PLANER
Cleveland Planer Works.

upright, which may be bolted on the other side of the frame to support a fourth tool head.

Figure 90 shows one of the largest planers ever built. This huge machine is 60 feet long and weighs 845,000 pounds. The table is 32 feet long, 14 feet wide, slides on three ways—the center, a, is a V-way and the two outside ones, b,b, are flat—and is driven with two steel "bull" wheels running in racks, c,c, 15 inches wide. The main drive is operated by a 100-horsepower motor, and the various feeds and other motions are operated

by independent motors, so that the total motor capacity is 207½ horsepower. The stroke of the table is 30 feet, the width between uprights 14 feet 4 inches, and the maximum height from the top of the table to the under side of the cross rail is 12 feet 3 inches. In the main, the machine is of the usual planer type, but it has, in addition, several unusual features. Slotter bars, d, with an 8-foot stroke, are incorporated in the rail heads, and one of these heads is provided with a power cross-motion for transverse planing. The machine is therefore capable of planing in three directions with one setting of the work upon the table.

A special type of large planer, shown in Figure 91, is used in the Midvale Steel Works for planing armor plates. Such work is so heavy that it is easier to move the machine with the cutting tool over the work than to move the work under the tool. The plate is set on the slotted bed between the horizontal rails, and the cutting tool, with the head and two uprights, is moved across the work. The motion of the two uprights is derived from heavy screws, which are arranged to operate in unison to insure parellelism of motion. In this case, the motions of the cutting stroke and of the various feeds are given to the cutting tool, and the work remains stationary.

Another screw-driven planer, shown in Figure 92, consists of a large vertical head, a, which has a horizontal motion along the lower bed. This head has vertical guideways and a heavy saddle, b, which carries the cutting tool. This saddle has a screw-operated vertical motion, which may be used for vertical cuts, the main head or upright, a, being clamped

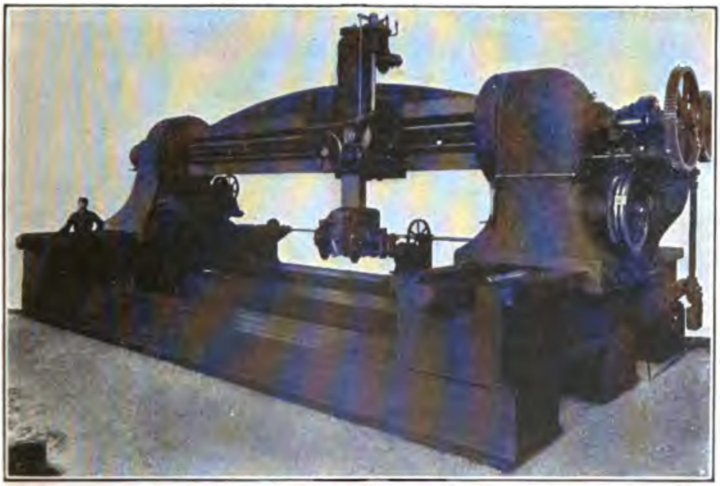


FIG. 90. 12 BY 14 BY 30-FOOT PLANER

FIG. 91. ARMOR PLATE PLANER

Niles-Bement-Pond Co.

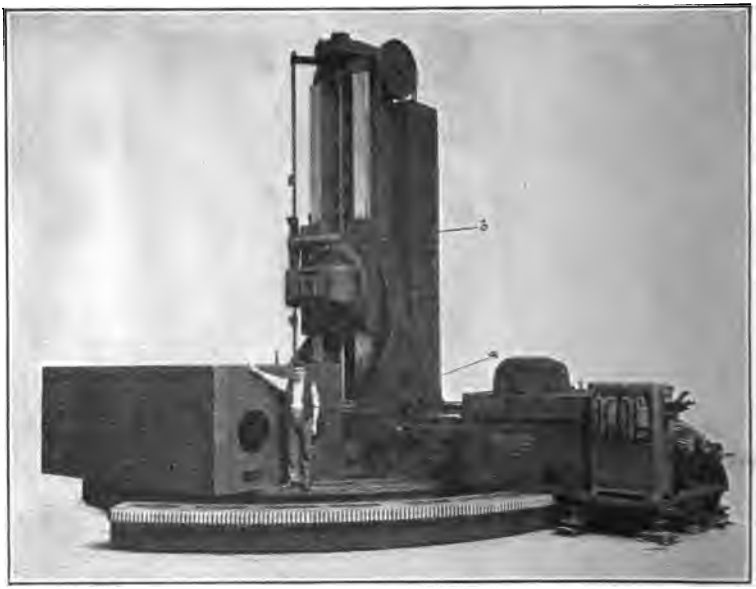


FIG. 92. SCREW-DRIVEN PLANER FOR WORK IN TWO DIRECTIONS
Niles-Bement-Pond Co.

to the bed; or, the saddle may be clamped to the upright and the head, a, moved sidewise to plane horizontal cuts. With this type of machine it is possible to make cuts at right angles to each other on the end of a heavy piece at a single setting. The machine is driven by a reversing motor.

Skill and judgment are required in clamping work to a planer table, for the work must not slip, must not spring in any direction under any of the cuts, and yet, however tight the clamping, it must not distort the piece in any way. Long-pitch, helical grooves may be cut on a planer by mounting the

piece on centers carried on the table, and giving to the work a rotary feed that is directly proportional to the longitudinal travel. Occasionally long, curved surfaces are planed by mounting on the table beside the work a "former," which causes the cutting tool to rise and fall as the table passes under it. The combination of the two motions generates an irregular cut which follows the curve of the "former." Frequently a number of cutting tools are set one behind the other in the tool-holder, to make successive cuts at the same pass from the rough to the finished surface. Other points in regard to the setting of planer tools have been mentioned in the chapter on "Cutting Tools."

The Shaper and Its Work.—The shaper was invented by James Nasmyth, and was for many years known among the English mechanics as "Nasmyth's Steel Arm." It was improved by Whitworth, who introduced the quick-return motion, and gradually took the form that is known today. Figure 93 shows a modern shaper. It consists essentially of a stiff, box-like frame carrying a vise or jaw mounted in front on a slotted table, or support, and capable of vertical and transverse motion under hand or power feed. The top of the frame is gibbed to receive a reciprocating ram, a, carrying on the front end a tool head which may be set at any angle and which has an independent hand-operated cross feed, b.

On the slide of this tool head is a tool post, and clapper box, c, similar to those used on the planer. The work is clamped in the jaws below, and the tool is reciprocated across the work. Except for the hand

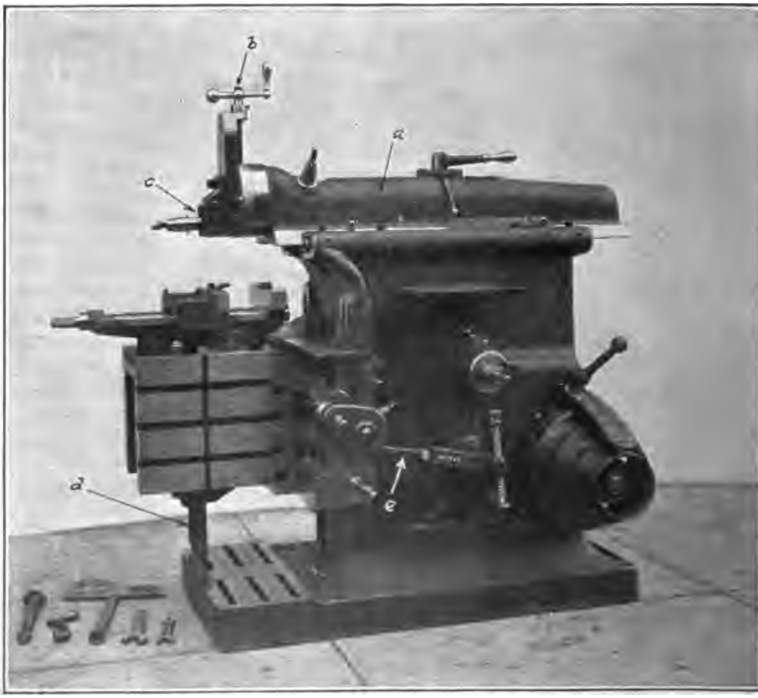


FIG. 93. STANDARD SHAPER
Gould & Eberhardt.

feed on the head, all the feeds are given to the work-holder. In the larger sizes of shaper, provision is made for an adjustable support, d, which extends from the table to the base, to preclude springing on heavy cuts. There are various types of shaper drives, all of them arranged to give a slow, powerful motion on the forward stroke and a quick return. The stroke may be varied from zero up to the full capacity of the machine, and the ram may be set forward or

backward with reference to the frame, so that short cuts may be made on different parts of a piece. The machine shown has the standard equipment, but special attachments are used, such as tilting and swiveling tables, which permit the shaping of a curved surface, and index centers, somewhat similar to those that will be described in connection with universal milling machines, which permit the cutting of long spirals. The shaper is a good tool-room machine, and is much better for small work than the planer. The type of drive used gives a more accurate control of the length of stroke than can be given by the shifting belts used on a planer. For accurate special work, such as die-sinking, it is an advantage to have the work stationary, in order that the action of the cutting tool, when machining to a line, may be closely watched.

Construction and Operation of the Shaper.—In most shapers, the tool cuts on the stroke toward the operator. In some types, however, this is reversed and the cutting is done on the inward stroke. The latter types are known as draw-cut shapers. An advantage that is claimed for them is the fact that the table and its connections are under compression rather than under tension. This is somewhat offset by the fact that the reverse is true of the joints in the tool head. Ordinarily the ram is operated by a Whitworth quick-return motion, as shown in Figure 95 and 96, or by a "pillar drive," as illustrated in Figure 94. The latter method is the more widely used today.

A vertical lever, or pillar, a, Figure 94, is pivoted

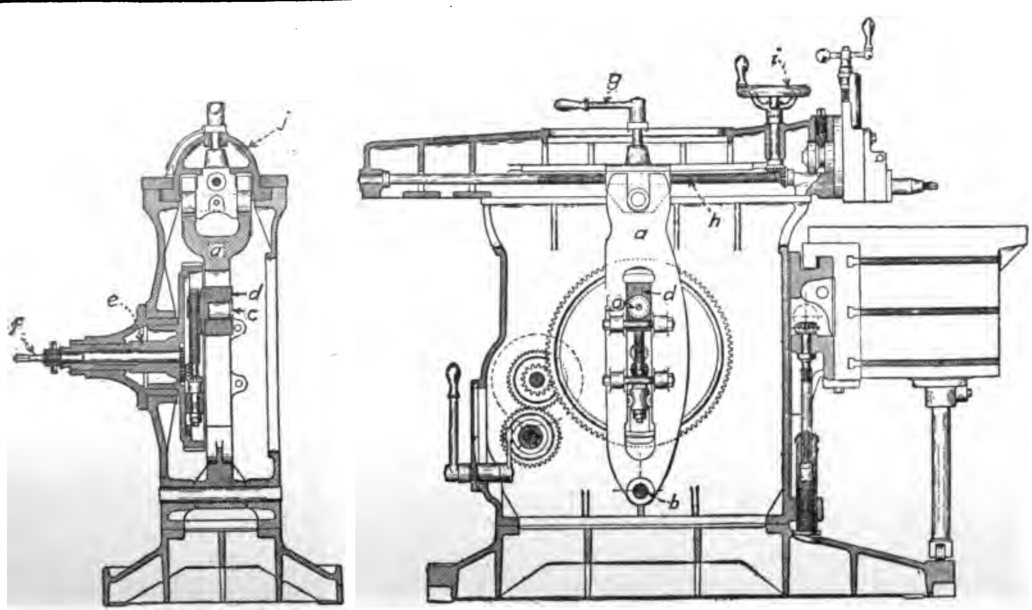


FIG. 94. SECTION OF A SHAPER
Cincinnati Shaper Co.

at its lower end, b, to the frame near the floor. The upper end is connected with the ram. This lever oscillates backward and forward about its lower end under the influence of a crank pin, c, and sliding block, d, which rotate about the shaft, e. When the crank pin and the block are turning forward on the upper part of their rotation, they are close to the ram, where they give the slowest movement and exert the greatest power. On the return stroke, they are in the lower half of the rotation and closest to the fulcrum, b, of the pillar, and consequently give a quick return to the ram above. The stroke length is varied by turning the shaft, f, which screws the block, d, and the crank pin, c, in toward the center, thus reducing the crank throw. The position of the ram is changed by loosening the clamp, g, and turning the screw, h, by means of the hand-wheel, i, which moves the ram forward or backward with reference to the lever, a.

The length of the ram is usually a little more than double the nominal size of the machine; the length of the guides on the top of the column in which it slides, is about 1½ times the length of the stroke of the machine. Theoretically, for the most even wear these should be of the same length, but practically this condition is not necessary, since short-stroke work is kept back on the table as near the column as possible. The cross-section of the ram is substantially that of an inverted letter U, as shown at j, Figure 94, with the sliding surfaces along the outer edge of the bottom. The cross rail slides directly on the front face of the upright; the table slides horizontally on the cross rail, and is provided with a transverse

power- and hand-operated feed. The rod that operates the power feeds is seen at e, Figure 93, on the side of the frame.

The Traversing Shaper.—Figure 95 shows a traversing shaper, a type of machine useful in finishing small spots on large, long, and unwieldy pieces. These may be clamped to the face along the front of the main frame in place of the tables shown in the illustration. The rams, a, of which there are several, are carried in sliding heads, b, which move along the guide on top of the frame; each ram is driven by a Whitworth quick-return motion, shown in Figure 96. The large gears, c, c, Figures 95 and 96, carrying the crank, are driven from small pinions, d, d, on a horizontal shaft just behind the upper corner of the frame. These pinions traverse sidewise with the sliding head, or carriage, and are eyed to this shaft with a sliding key. The shaft is therefore able to drive the mechanism of the carriage at any position along the top.

Figure 96 shows a detail of the driving mechanism. The large gear, c, which rotates uniformly, turns in the head, b, on the center, e. The slotted crank, f, which drives the ram through the pin, g, turns about the center, h, which is also fixed with respect to the head, b. The crank, f, is driven by a pin, i, fixed in the gear, c. Since this pin, i, turns about e, its path is circular, but it is eccentric to the center, h, of the crank. That portion of the motion of the pin, i, which is above the horizontal line through h, causes the return motion, indicated in Figure 96 as the "arc of return." The motion below this horizontal line,

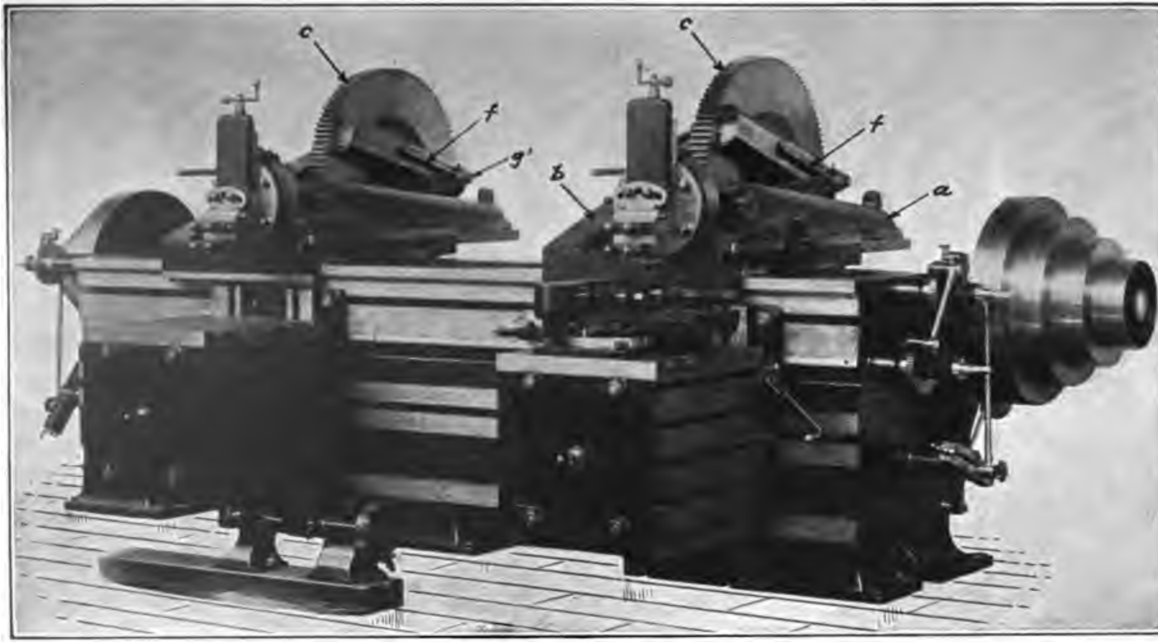


FIG. 95. TRAVERSE SHAPER
Cincinnati Shaper Co.

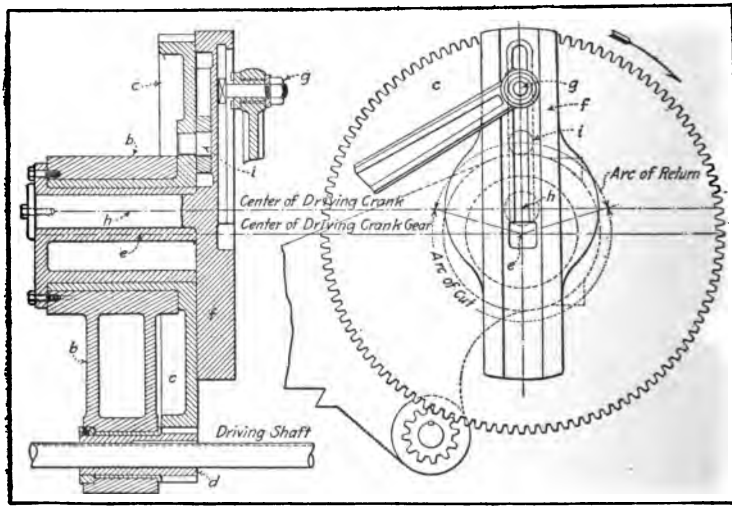


FIG. 96. WHITWORTH QUICK-RETURN MOTION

indicated as "arc of cut," causes the forward motion. Since the pin is moving at a constant rate, and the arc of return is much shorter than the arc of cut, the return motion is made in much less time than the forward motion. If the pin, g, is out at the end of the crank-slot, as at g′ in Figure 95, the ram is taking a full stroke. If it is in close to the center, the ram is taking a short one.

The base in Figure 95 is shown equipped with tables; these convert the machine into two standard shapers, which may be used for small work. On the floor is an index center which may be set on the table for planing circular work along a line parallel to its axis. The table to the right carries on its upper face a swiveling vise, which may be set at any angle in the

plane of the face to which it is clamped. Since the tables may be swiveled in a vertical plane, the combination of the two circular motions enables the shaper to plane at any angle.

The Vertical Shaper, or Slotter.—The slotter, or vertical shaper, Figure 97, is, as the latter name implies, a shaper in which the motion of the ram is vertical, instead of horizontal. On these machines the work is carried on a slotted, circular table, a, which is provided with a rotary feed operated by hand or machine power. The table, and its base, b, have a transverse hand or power feed on a saddle, c, which, in turn, has a feed in and out on the main base of the machine. This combination of feeds permits the shaper to cut faces at right angles in two directions, and also to plane circular faces. The last is particularly useful in machining curved surfaces that have a projection which precludes their being turned on a lathe.

The ram in this machine can be tilted outward for any angle from zero to 5 degrees, an advantage that is of particular value in the cutting of tapered keyways. Like the shaper, the ram is driven by some form of quick-return motion. Any part may be clamped rigidly to its neighbor, and, by a combination of two of the motions, oblique or irregular outlines may be cut. It is therefore often used for finishing the profiles of irregular pieces.

Figure 98 shows a machine especially adapted for key-seating work. The slotter is often used for this purpose. The key seater is a single-purpose machine, used for cutting the keyways on pulleys, gears, and

FIG. 97. VERTICAL SLOTTING MACHINE
Pratt & Whitney Co.

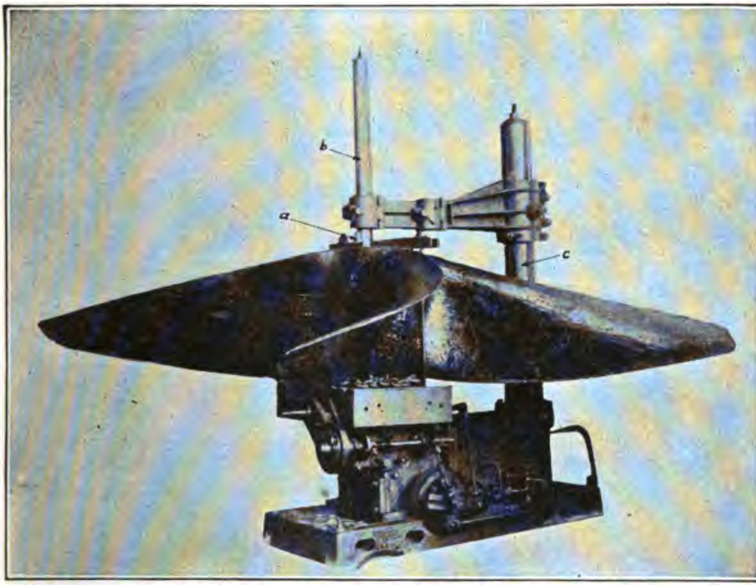


FIG. 98. KEY-SEATING MACHINE
Baker Bros.

so on, which have already been bored and faced. The illustration shows a large propeller set in place. The cutter, a, in this machine is carried in the round bar, b, which extends up through the hub. It is operated by a rack-and-pinion driving mechanism located in the frame below and does its work in a draw cut on the downward stroke. The cutter has a guide carried by the arm which extends forward from the upright, c, at the back of the machine.

CHAPTER XVIII

MILLING MACHINES

Some Advantages of the Milling Process.—The milling cutters, in Chapter XII, has grown steadily in importance for the past fifty or sixty years. Professor C. H. Benjamin* has stated some of its advantages as follows:

> Twenty-five years ago the milling machine was regarded as a special tool, and the bulk of straight work was done on the planer and the shaping machine. Today the milling machine is in the lead, and is preferred by most manufacturers for all work within its range. The reason for this is the simple fact that this machine will do more work, or will do the same work with a greater degree of accuracy. The milling cutter is a multiple tool having many cutting edges, and it has no return motion, but cuts all the time. Furthermore, the possibility of shaping regular outlines by one operation, and of repeating that operation and thus duplicating the pattern indefinitely, gives the milling machine a great advantage over machines using a single point tool. Even in the simple operation of facing plane surfaces, the milling cutter with inserted teeth has made records which no reciprocating machine can hope to equal. The fact that both types of machines are today working side by side in the best shops, shows that each is finding its own proper field and succeeding in that field.

The Work of the Milling Machine.—The milling machine, with the automatic lathe, is relied on to do the bulk of the work in plants that are manufacturing on an interchangeable basis. When first used it

* Modern American Machine Tools; C. H. Benjamin, p. 198.

was confined to light work, but of recent years has been applied more and more to larger and heavier operations. It is used for the simplest kind of repetition automatic work and, in the form of the universal milling machine, for the most delicate and skilful operations. The universal milling machine is the most characteristic machine in the tool room. For manufacturing purposes, the milling process is used mainly for producing large quantities, as the tools are comparatively expensive, require skill in setting, and are more restricted in their use than lathe tools. On the other hand, accurate milling operations can be performed by comparatively cheap labor, the wear on the cutters is slow, and a great many kinds of cuts may be taken which would be difficult to produce commercially in any other way. Some idea of the variety of cuts that it is possible to make may be gathered from the collection of milling cutters shown in Figure 99.

Origin and Development of Milling Machine.—Probably the first milling machine ever built—certainly the oldest now in existence—is at present in the museum of the Sheffield Scientific School of Yale University. It was built by Eli Whitney some time before 1818, and was used for the manufacture of gun parts for the United States Government. This machine is a very simple affair and could never have been used for anything but light, straight cuts. The "lineal descendant" of this machine embodying the same general arrangement but greatly refined in design, of course, is the hand milling machine shown in Figure 100. It has a box-shaped body, and a head somewhat sim-

FIG. 99. COLLECTION OF MILLING CUTTERS

ilar to a lathe headstock, which is cast integral with it. This head carries a spindle, which is driven by a stepped cone pulley. The small end of the pulley is toward the front bearing, as this position permits a firmer bracing for the front bearing, which takes the end thrust. The front of the column is provided with vertical ways, and carries the knee, a. The up-and-down motion of the knee is operated by the handle, b, and a rack and pinion, which does not show.

Adjustable stops are provided on the side of the guide, as shown, which limit the motion as may be desired. On the top of the knee is a saddle, c, which may be moved in and out from the frame of the machine by the adjustable screw, d, and clamped in any position. On the saddle is the table, e, which has a transverse movement under the milling cutter, operated through the hand lever, f, and the pinion and rack, as clearly shown. The table is slotted to carry a standard milling-machine vise or special fixture to hold the work.

In operating the machine, the attendant sets the work in the jaws, raises the knee and the table by the handle, b, to a point determined by the side stop, and then feeds the work horizontally with the other handle, f, to a definite point set by the stop, g, at the front of the table. The weight of the knee and the table is counterbalanced by a weight within the column, so that the operator does not have to lift them at each operation. These machines are adapted to milling the small parts of guns, sewing machines, typewriters, and the like.

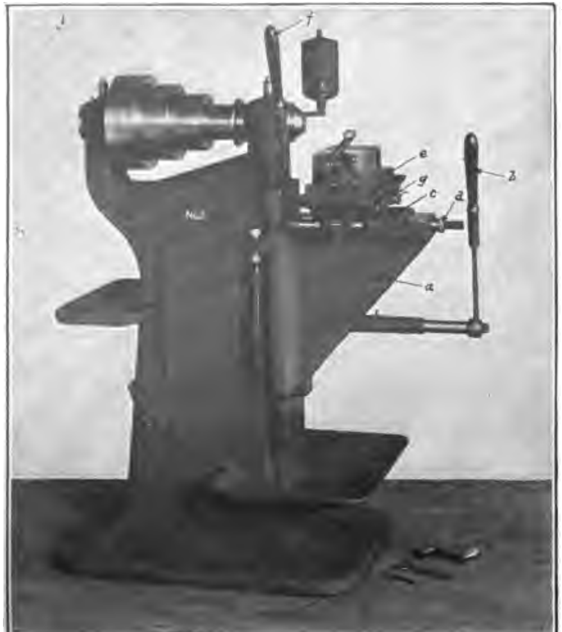


FIG. 100. HAND MILLING MACHINE
Pratt & Whitney Co.

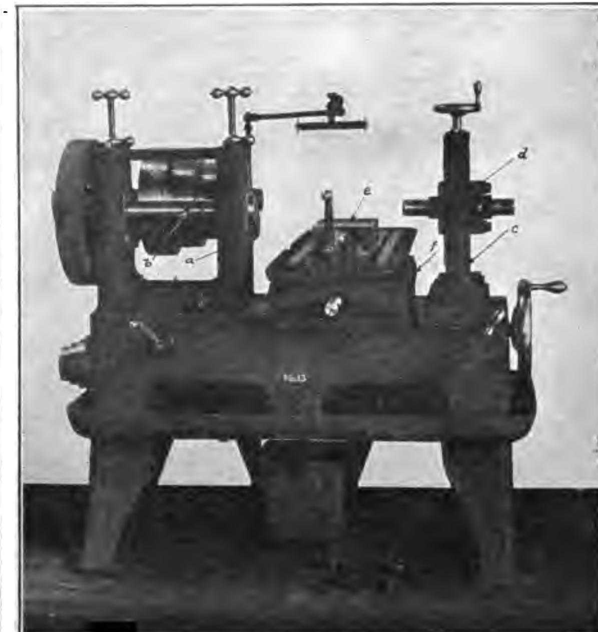


FIG. 101. LINCOLN TYPE OF MILLING MACHINE
Pratt & Whitney Co.

The Lincoln Type.—About 1850, F. W. Howe and R. S. Lawrence, of Robbins and Lawrence, Windsor, Vermont, designed a miller which was the forerunner of the Lincoln milling machine, shown in Figure 101. They brought this to Hartford, and fifty machines of the same general design were ordered from the Lincoln Iron Works of that city for the Colt Armory, which was erected in 1855. The machines were built under the direction of F. A. Pratt and Amos Whitney, who later formed the firm of Pratt and Whitney. Mr. Pratt added certain improvements—such as the screw drive for the main table feed—and various details. Many thousand machines of this design have been built since that time; they are known, even in Europe, as the Lincoln type of miller, from the name of the builders of the early machines.

The Lincoln miller consists of a short, stiff bed, with a headstock, a, either cast or bolted to it, which carries a live spindle, b, and its driving mechanism. At the other end of the machine is an upright, c, which carries an adjustable block, d, supporting the outboard end of the arbor that carries the milling cutters. The spindle and the block are adjustable vertically, and accommodate work of different heights. The work is held in a jaw, e, or special milling fixture, which is clamped to the movable table between the headstock and the outboard guide. The upright, c, and the saddle, f, carrying the table are adjustable lengthwise on ways at the top of the bed. The saddle has no feed in this direction but is clamped to the bed when set in the desired position.

The table has a cross feed operated by hand or

power, which moves the work under the milling cutter. In the very early machines, this was operated by a pinion and a toothed rack on the under side of the table. This arrangement caused the feed to chatter badly under heavy cuts. One of the chief improvements made by Mr. Pratt was the substitution of a screw feed, g, which operates through a nut secured to the saddle. While seemingly a minor improvement, it really made the success of the machine. This type of miller is used for straight milling cuts on repetition work. It resembles in many respects the horizontal boring machine shown in Figure 75—in fact, in many instances the same operations may be performed on either machine. The spindle, b, on the Lincoln miller, however, has no traverse motion, and the only feed of the table is across the machine. Its use is therefore confined to operations that can be performed by a single pass of the work under the cutting tool—but it is remarkable how much can be done in this way. The simplicity of the machine is an element of accuracy and permits of its operation by unskilled attendants.

The Briggs' Type.—Figure 102 shows a machine for the same kind of work as the above, in which the vertical adjustment is in the table instead of in the spindle. In this machine the frame consists of two uprights cast together at top and bottom. Between these, carried by the guideways, a, is a saddle, b, which may be adjusted vertically by the screw, c, underneath. This in turn carries a slotted table which moves in and out under hand or power feed, as in the Lincoln miller. The cutter arbor, d, is fixed

FIG. 102. BRIGGS TYPE OF MILLING MACHINE
Gooley & Edlund.

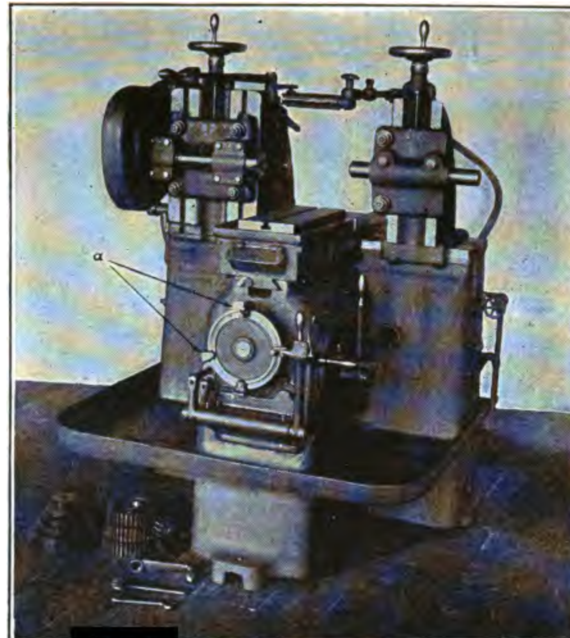


FIG. 103. AUTOMATIC MILLING MACHINE
Pratt & Whitney Co.

in position; the support for the outer end is a bronze sleeve in the removable bushing, e, which is held in the frame by an expanding belt, f. The space in the base below is used as a tank for cutting lubricant.

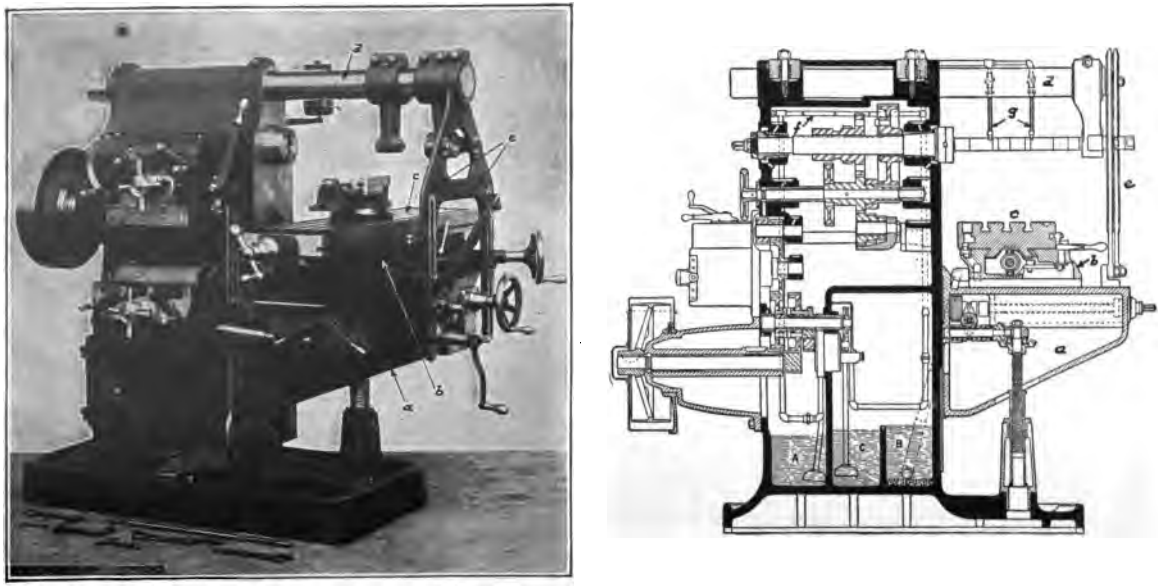
Modern Development of Lincoln Miller.—Figure 103 shows a modern development of the Lincoln Miller. It is an automatic machine of heavy construction throughout. The uprights carrying the spindle and the arbor support are parabolic in outline, and somewhat resemble the uprights of a planer; the strain to which they are subject, in both machines, is very similar in nature. The various motions on the machine may be operated by the hand levers in front; in regular operation, however, they are automatic, and are controlled by the circular plate shown at the front of the machine. Adjustable dogs, a, may be set in position around the edge of this plate, to throw in and out the levers that control the reverse and feed mechanism. The work starts from a position well to the front—where the fixture may be loaded without danger of injuring the hands of the operator—and approaches the cutter with a rapid forward traverse. Just before the work engages the cutter, the slow feed is automatically thrown in.

After the milling operation has been completed, the table is automatically returned quickly to its original position, stops at the end of the motion, and waits for the operator to load the fixture and start the forward feed. As the table starts on the return traverse, it is dropped somewhat to permit the work to clear the cutter as the table goes back; this precaution prevents any marring of the finished surface. Then,

as the table approaches the end of the return travel, it is automatically elevated to its cutting position and remains at this height during the cutting traverse. Because the control of these motions is entirely automatic, one operator can attend to several machines. The cutting feeds, by means of change gears, may be varied to suit the requirements, and the table feeds are entirely independent of the spindle speeds.

Column-and-Knee Type.—The plain miller of the column-and-knee type, Figure 104, is a refinement of the hand miller, and is usually much larger and equipped with power feeds in all directions. It is more flexible than the Lincoln miller, as the table has not only a transverse feed, but a vertical and an in-and-out motion. Some of these machines have both hand and power feeds for all three of these movements; some, for the longitudinal and transverse movements only; the vertical motion is operated by hand; in still others, only the longitudinal feed is power-driven. Figure 105 shows a vertical section of another machine of the same type. Clamps are provided for locking the knee, a, to the main frame, the saddle, b, to the knee, and the table, c, to the saddle, when motion at any of these points is not required. A heavy bar, d, at the top of the machine can be adjusted in and out, according to the demands of the work. This bar carries an outboard support for the milling arbor, and is itself stiffened by braces, e, extending from the outer end down to the end of the knee.

Modern machines of this type are driven by a single-speed pulley, and the speed variations are ob-



FIGS. 104 AND 105. VIEW AND SECTION OF COLUMN-AND-KNEE TYPE OF PLAIN MILLING MACHINE

Cincinnati Milling Machine Co., and Kearney & Trecker.

tained by means of change gears. All the feed movements are power-operated, and are provided with stops to limit the motion. The sectional view shows the method of lubrication by which the bearing lubricant stored in the reservoir, A, is pumped to the top of the machine, where it is distributed through a perforated pipe, f. The cutting lubricant is stored in the reservoir, C, is pumped to the top of the machine, and from there is distributed over the cutters and the work through adjustable nozzles, g. Then it is returned to the reservoir, B. The latter acts as a settling tank for the chips, which sink to the bottom; the lubricant runs over the top of the partition into the reservoir, C.

Vertical Miller.—The vertical type of plain miller is in many ways similar to the column-and-knee type, so far as the arrangements of the table are concerned. The spindle, however, stands in a vertical position, instead of being horizontal. It may be carried in a head, adjustable with respect to the main body of the machine, as shown in Figure 106, or the head may be cast solid with the frame. The vertical type of machine clearly embodies the principles of the drilling machine. The spindle and the table are similarly located, and the cutter is mounted on the lower end of the spindle. The table, however, has a series of movements not found on the drilling machine.

For such work as face milling, die-sinking and the cutting of profiles, the vertical-spindle machine has many advantages as compared with the horizontal type. In many cases a piece may be fastened directly

FIG. 106.
VERTICAL MILLING MACHINE
Brown & Sharpe Mfg. Co.

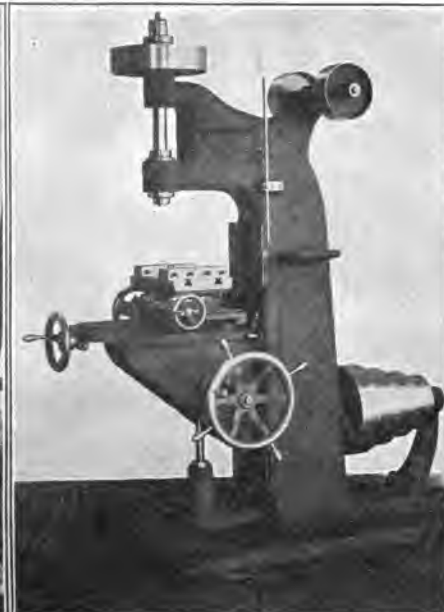


FIG. 107.
DIE-SINKING MACHINE
Pratt & Whitney Co.

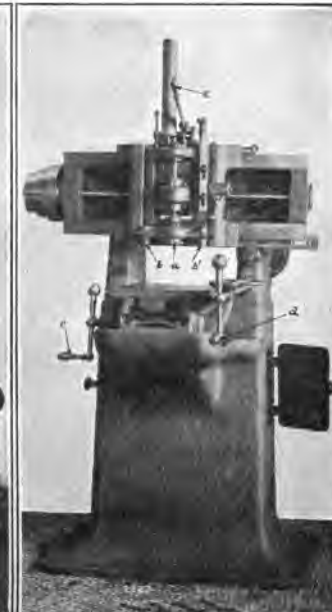


FIG. 108.
PROFILING MACHINE
Pratt & Whitney Co.

to the top of the table, whereas fixtures would be necessary if the work were done on a horizontal machine. Also, the operator can see his work at all times, and can follow any irregularities of outline much more readily than when he uses the horizontal type.

The die-sinker, Figure 107, is a type of vertical milling machine especially adapted to the purpose indicated by its name. The dies are clamped in the jaws on the table, and a small end mill, formed or plain as the case may be, is carried in the lower end of the spindle. Longitudinal, transverse and vertical movements, as well as horizontal rotation, may be given to the work. Frequently a swiveling vise is used, which permits of angular adjustments in a vertical plane as well. These feeds are operated only by hand, as this type of machine is used by skilled tool makers who follow the outline laid out on the surface of the die, and scarcely any two jobs are the same. Power feeds would therefore be almost useless. As the cuts used in die-sinking are almost invariably light, the spindle is driven directly, with gearing, by a half-turn belt from the cone pulley below.

The heavier type of machine, shown in Figure 106, is used for manufacturing purposes; it is provided with a powerful drive that has the necessary speed changes, and so on. Frequently machines of this type are provided with a circular table that has a rotary power feed. Figure 106 shows such a set-up—the heavy face-milling cutter is machining the bottoms of flatirons, which are arranged around the top

of a fixture and given a continuous feed. As the feeding motion is comparatively slow, the finished work may be taken out and new pieces may be substituted while the cutting is going on. The work of the machine is therefore continuous.

Profile Milling Machine.—By giving the milling cutter some desired contour, and moving the work past it in the necessary irregular path, very irregular surfaces may be cut. When such surfaces are to be produced on a manufacturing basis, the profile milling machine, shown in Figure 108, is used. In this machine the cutting tool is inserted in the end of the spindle, at a, and a hardened steel guide pin is clamped into the head at b or b′. As a part of the fixture—holding the work, and at one side of it—is a former plate, which has a shape similar to that of the piece to be milled. By operating the handle, c, which moves the table in and out, and the handle, d, which moves the head sidewise, the operator causes the pin, b, to follow the curved edge of this "former." The work, accordingly, moves past the cutter in the irregular path required.

Figure 109 shows the frame of an automatic pistol that contains several cuts of this nature. A formed milling cutter is used which has a concave outline of the same curve as the edge. The work is fed so that the cutter moves along the piece from a, around the outside of the finger loop, and down the handle to b. It may then be guided around to the back of the handle, along it, and off the work at c. The former plate which guides this cut will have a shape similar to the path of the milling cutter around the stock.

FIG. 109. AN EXAMPLE OF PROFILING WORK

A second and smaller cut, of a similar nature, is shown on the side of the frame from d to e; there is, of course, a corresponding one on the opposite side. A third profiling cut will be made around the inside of the finger loop, which is still rough on the piece shown.

Almost any contour can be given to the milling cutter, and it can be made to travel in almost any path —the only condition is that the radius of the curved surface in corners, such as f and f′, must be less than the radius of the milling cutter. For internal cuts, such as the one inside of the finger loop, provision is made for lifting the guide pin and cutter, by means of the lever, e, above the plane of the work and the "former", and dropping them down again to the zone in which the cut is to be made.

Frequently profiling machines are made in which the upper rail is longer and carries an additional head and spindle with its own guide pin. One of the

heads is used for a roughing cut, and the other for a finishing cut. Both are made in one setting of the piece, finishing it accurately to dimensions; thus hand fitting is done away with. It is obvious that this type of machine can produce interchangeably and on a manufacturing basis, some very irregular shapes.

Universal Milling Machine.—The aristocrat among milling machines, and in fact in the whole field of machine tools, is the universal milling machine, one of which is shown in Figure 110. There is scarcely a type of cut known in the machine shop which cannot be made on this machine. It was first developed by Brown & Sharpe in 1861, for milling the flutes of a twist drill. The machine has the column, knee, and saddle of the type shown in Figure 104. The table, a, however, is arranged to swivel horizontally through a very considerable angle, and is provided with an accurately graduated measuring circle, b.

On the table is a so-called universal head, H, shown in Figures 110, 111, and 112. This head corresponds in some ways to the head-stock of the lathe, although it is wholly different in design. The adjustable bracket, c, which supports the outboard end of the work, corresponds in function to the lathe tail-stock, and the table of the machine to the lathe bed. In a lathe the work revolves under the tool, and the tool is fed past the work. In this case the milling cutter revolves, and the work, carried on the two centers, d and e, may be set at an angle with reference to the cutter and fed past it or rotated—or these two motions may be used simultaneously.

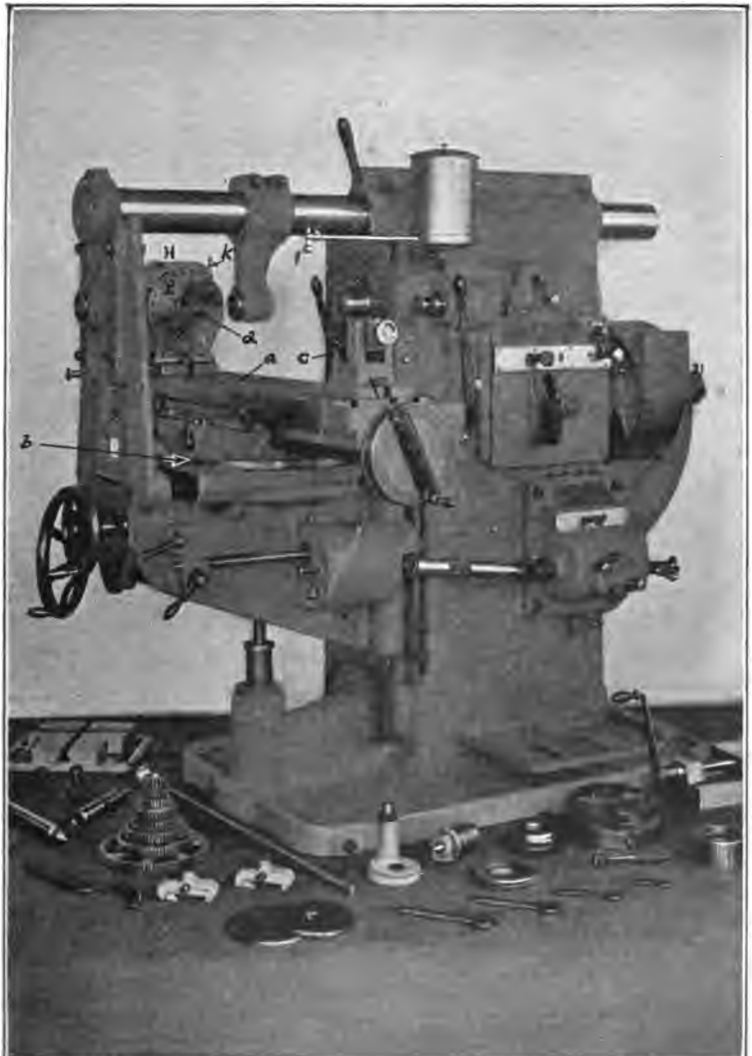
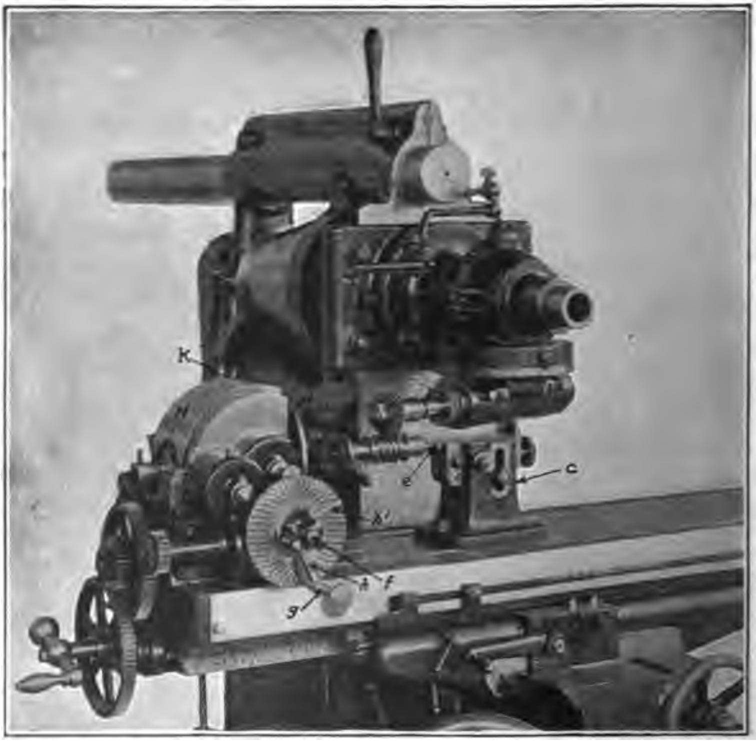


FIG. 110. UNIVERSAL MILLING MACHINE



FIGS. 111 AND 112. INDEXING HEADS

The lower view shows a head arranged for six spindles. Brown & Sharpe Mfg. Co.

Milling Teeth of Spur Gear.—If the centers are set at right angles to the axis of the spindle, and the table is fed sidewise, the cutter will mill a straight slot parallel to the axis of the piece. The table may then be returned, the work may be indexed through a desired angle by means of the mechanism in the head, and the cut may be repeated. Such, for instance, would be the "set-up" for milling the teeth of a small spur gear. Or the table may be clamped in a definite position under the cutter, and the work given a continuous rotary feed on its centers without lateral change of position. By this method a circular slot would be milled around the work.

Milling Long Spirals.—For milling long spirals—such as the flutes of a twist drill, for which the machine was originally designed—the table is turned horizontally to the pitch angle of the groove, and the swiveling joint clamped in that position. The drill, carried between the centers, d and e, is fed longitudinally with the table at the angle so set, and at the same time given a rotary power feed by means of the head, H. The combination of these two movements generates the helical cut required. The work may then be run back to its starting position, the spindle, d, and the drill being cut may be indexed 180 degrees, the feeds thrown in again and the second groove cut.

Control of Rotary Motion.—The rotary motion of the spindle in the dividing head is under the influence of two controls, one of which performs the function of indexing between the several cuts, the other of imparting uniform rotation during the cut. The

spindle that holds the center, d, carries, inside of the head, a worm wheel and is operated by a hardened steel worm located on the shaft, f, to which the index crank and handle, g, are fastened. When the worm is turned by means of the index crank, the indexing is accomplished. The index plate outside is drilled with six rows of small holes. The crank is turned a certain number of holes, and a spring pin in the handle engages the hole that gives the angle desired. Two adjustable arms, h, h′, may be set to take just the number of holes required and minimize the chance of making a mistake by turning the handle of the indexing crank to the wrong hole. This operation is performed before the cut is begun, to turn the work through the angle necessary to locate the cut.

Continuous Rotary Feeding.—For the continuous rotary feeding during the cut, the index plate and the worm are driven together from the table feed-screw through the train of change gearing shown at the end of the table. This may be done while the index pin is in any hole of the plate. Through the interposition of change gears shown, the rate of rotary feed in relation to longitudinal traverse may be varied to control the angle of the spiral generated. For rapid indexing, in cutting taps, reamers, and so on, the worm inside may be disengaged and the spindle may be turned by hand. The principal divisions most commonly used are determined directly by the single row of holes in the index plate, i, which are engaged by a pin operated by the handle, k.

It is possible to tip the head in a vertical plane so that the spindle, d, can be set at any desired

angle from 10 degrees below the horizontal to 5 degrees beyond the perpendicular, without affecting the operation of the mechanism. This tipping of the head renders it possible to make cuts on conical surfaces. With special fixtures, the dividing head may be used to index more than one piece of work at one time. Figure 112 shows a head coupled to a special fixture so as to index six pieces at once for milling the spiral slots in push screw-drivers.

Various forms of heads are made for different purposes. Some for spiral milling are without the vertical swiveling, and the center of the spindle, d, remains at all times horizontal; in others, the indexing heads are made without either automatic driving mechanism or vertical swiveling and are used for straight work, such as the cutting of spur gears. The horizontal swiveling of the main table may be omitted, and the tool driving head may be swiveled instead. With such a head, the work which otherwise would require a universal machine can be done on one of the plain column-and-knee types, as shown in Figure 111, where the work is at right angles to the main axis of the machine, and the cutter axis, instead of the table, is set at the pitch angle.

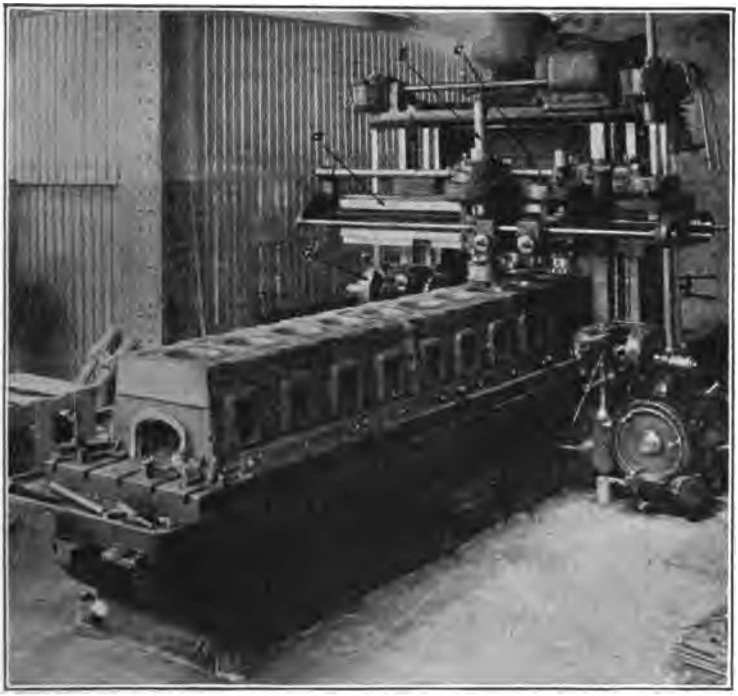
The universal miller is distinctly a tool-room machine. The adaptability which enables it to perform almost every type of machining operation necessarily involves refinements of design and delicate adjustments that require skilful handling.

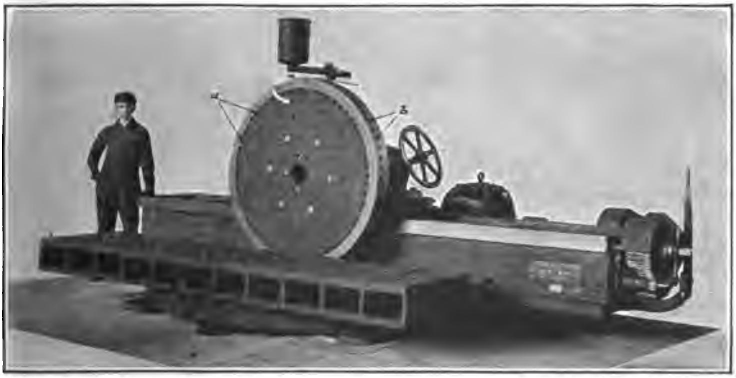
Planer Type of Milling Machine.—Nearly all the machines described are for small or moderate-sized work. The milling principle, however, has been ap-

plied also to large work and heavy production. Figure 113 shows a machine of the so-called planer type. The reason for the name is obvious, as the general appearance of the machine is closely similar to that of the planer. There are the main bed, the traversing table, the uprights, the cross rail, and the tool heads of the standard planer. Its action however is materially different. The tool heads of a planer contain single-edged cutting tools which have no motion other than the feed. The cutting heads of this machine carry revolving spindles and milling cutters usually, but not always, of the face-milling type.

In the planer the table and the work move back and forth under the cross rail many times while a cut is being made. In this machine the action is like that of a Lincoln miller, Figure 101. The work moves forward slowly at the speed of the feed, and passes under the cutting tool but once. The cutting action in this case is continuous, instead of intermittent as in the case of the planer. Machines of this type are made in sizes from 20 inches square by 8 feet traverse, to 10 feet square by 30 feet traverse. For special manufacturing operations, they are often made with heavy fixed cross rails cast solid with the uprights.

In the machine shown, the cross rail, a, is adjustable, and one of the vertical spindles, b, is equipped with a vertical or boring feed. The other head, c, is a straight milling head. The cross rail may carry one milling head, or two, according to the size of the machine, and frequently milling heads, as at d, are provided on one or both of the uprights. These ma-





FIGS. 113 AND 114. PLANERS

The upper, Fig. 113, is a milling machine of the planer type, built by the Ingersoll Milling Machine Co. The lower, Fig. 114, is a rotary planer made by Niles-Bement-Pond Co.

chines can do nearly all the work that could be done by a planer of corresponding size, and will do it much more rapidly, finishing it from the rough piece in a single pass. They are, however, distinctly a manufacturing type of machine, and are not so well adapted for special jobbing work as the planer.

A machine of the proportions shown is by no means confined to operation on long narrow work. Special fixtures are often provided to mount a series of castings—as automobile cylinders, for in-tance—in a long row one behind another. When the fixtures have been filled, the table is started past the cutters on the forward feed. As each piece passes the cutting heads, it is finished. Owing to the slow feed of the table, the pieces that have been passed under the rail may be removed while the cut is in progress and new work may be substituted. When the last piece in the row is finished, the quick reverse traverse may be thrown in, the table returned, and a new cut started on the fresh pieces that have been put in at the front end of the table. While these are being cut, the last pieces may be replaced, at the other end of the machine, so that, although the feed is reciprocating, the cutting action may be almost as continuous, as in the rotary feed shown in Figure 106.

Rotary Planer.—Another machine, known as the rotary planer, shown in Figure 114, is in reality a face-milling machine for machining large flat faces. The work is clamped to the fixed table in the front of the machine, and a large revolving head, mounted on the travelling carriage, passes along the table.

The head carries a series of single-edged tools of the planer type, which are inserted in the holes, a,a, in the face, and are secured by means of screws operated from corresponding holes, b,b, in the rim.

The carriage, with its revolving head, is slowly fed horizontally along the ways—the cut begins at one side of the piece and passes progressively across the face. It will be noted that the cutting tools drop slightly below the level of the bed on which the work is clamped, to insure that the bottom is finished, and the width of the face of the work must not be greater than the diameter of the circle of the cutting tools. Machines of this type will finish flat faces on large castings with astonishing rapidity.

CHAPTER XIX

GEAR-CUTTING

Two Systems of Tooth Forms.—The cutting of gear teeth is one of the important operations in the machine shop, and a wide variety of machines have been developed for this purpose. The kinds of gears are so varied and the mechanical motions required to cut some of them are so intricate, that in the design of no other type of machine tool have more skill and ingenuity been displayed. Before treating of the machinery, it is necessary to consider some points in regard to tooth forms and types of gears.

Two systems of tooth forms have had wide use; they are known, from the curves that govern their shapes, as the cycloidal and the involute. Teeth with sides formed of these curves will transmit motion from one gear to another, quietly and smoothly, at a constant velocity ratio. In both systems, the teeth are designed with reference to a circle called the pitch circle (see Figure 115), and the action of the teeth is designed to duplicate exactly the motion that would be derived from the rolling of two pitch circles together. While tooth forms are laid out as lines related to a pitch circle, the gear always has a finite thickness, and the sides of the teeth are actually surfaces related to a pitch cylinder, or cone,

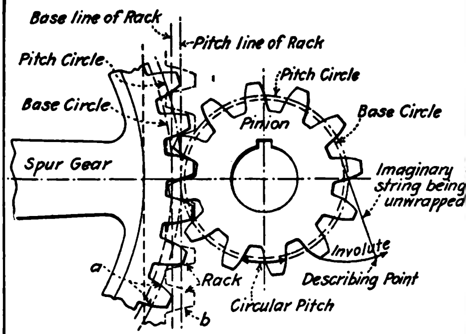


FIG. 115. PAIR OF SPUR GEARS - SHOWING TOOTH SURFACES FORMED FROM INVOLUTE CURVES

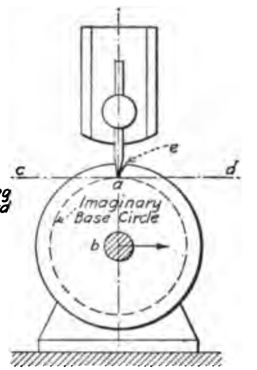


FIG. 118. THE DESCRIBING-GENERATING PRINCIPLE OF FORMING GEAR TEETH

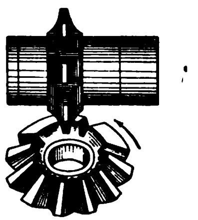


FIG. 116. CUTTING A BEVEL GEAR BLANK WITH A FORMED MILLING CUTTER

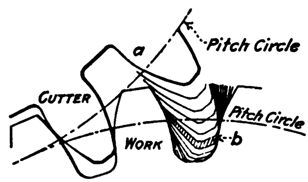


FIG. 119. THE FORM-GENERATING PRINCIPLE OF FORMING GEAR TEETH

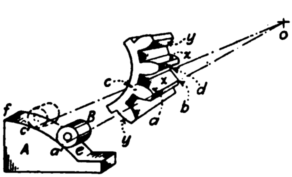


FIG. 117. THE TEMPLATE PRINCIPLE OF FORMING GEAR TEETH

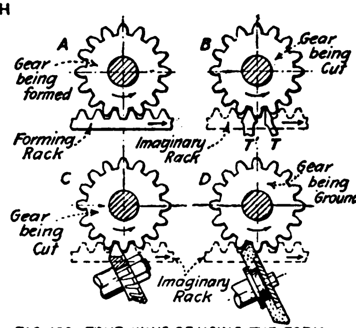


FIG. 120. FOUR WAYS OF USING THE FORM-GENERATING PRINCIPLE

FIGS. 115-120. CUTTING GEAR TEETH

of which the pitch circle is a cross section. The theory of these systems is somewhat intricate, and need not be given here.* The cycloidal system is the older; it was developed about 1830, but it is now falling into disuse, because teeth formed on the involute system are simpler to generate and stronger. Although formed milling cutters may be obtained for both kinds of teeth, practically all machine-cut gearing is now based on the involute system; only that system, therefore, will be considered.

Spur Gears.—The gears in general use belong to one of the following four types: spur gears, helical gears, bevel gears, and worm gears. Spur gears transmit motion between parallel shafts, and their action in every way duplicates that of two pitch cylinders when rolling upon each other (see Figure 115). Spur gears may have as few as twelve teeth. Theoretically, they may have still fewer, but practically this is the limit, since the tooth form grows weak and other troubles are encountered when fewer teeth are used. Small spur gears are called pinions when they mesh with a larger gear, which is ordinarily termed the spur. As the size of the wheel grows larger, the sides of the teeth, a, become flatter until the limit is reached in a rack or straight bar, in which the sides have become a plane surface, at b. Usually two gears run on the outside of each other, as in Figure 115, or a and b, Figure 126. Occasion-

* Those who wish to follow up this subject are referred to some standard book on mechanism, such as "Elements of Mechanism," Schwamb and Merrill; "Mechanism," Keown; "Treatise on Gear Wheels," Geo. D. Grant, or some of the standard works on machine design.

ally, however, a small pinion will engage with the inner surface of the rim of a large gear, as c and d in Figure 126, in which case the large one is called an internal gear. Figure 126 also shows a rack engaging a pinion, f. In spur gearing the teeth are straight, parallel to the axis of the gear and to each other, and of uniform size and shape throughout the whole length.

Helical Gears.—These gears are similar to spurs, as regards both use and general design, except that the teeth, instead of being straight, are wrapped around the pitch surface, each as a uniform helix. Although not parallel to the axis, they are parallel to each other and of uniform size and shape, as in spur gearing. Helical gears are smoother in action than the ordinary gear, and, as a result of the improved methods of manufacturing them, they are coming into increasing use.

Bevel Gears.—These gears are used for transmitting motion between axes which are in the same plane but not parallel. The teeth, theoretically, are formed on pitch surfaces that are rolling cones, instead of rolling cylinders as in spur gears, the apexes of the cones coinciding with the intersection of the two axes of the gears. The cross-section of a spur-tooth gear is the same in any plane at right angles to the axis. The cross-section of a bevel gear grows smaller and smaller as it approaches the apex of the pitch cone, since all the elements of each tooth center in toward it (see Figure 117).

Worm Gears.—A worm gear is a toothed wheel operated by a screw that meshes with it; the screw

lies tangential to the face, with its axis at right angles to the axis of the wheel. A worm and worm wheel are shown at g and h in Figure 126—in cross-section in the main view, and in plan in small view above. In the upper view the teeth on the worm wheel, though not shown so, in reality extend entirely around it. This type of gear is very useful for rapid reductions of speed, and for fine dividing and indexing when it is necessary to control the angular motion with great accuracy.

There are various other forms of gear wheels, such as skew gears and hyperbolic gears, but since they are not extensively used they need not be considered here.

Formed-Tooth Principle.—A gear-cutting machine operates on one of the four following principles: the formed-tooth principle, the template principle, the describing-generating principle, and the form-generating principle.

Of these the oldest, simplest, and most widely used is the formed-tooth principle. A "blank," which consists of the gear wheel bored, faced, turned, and ready to be cut, is mounted on a suitable arbor, and the space between two teeth is removed by a cutting tool that has been accurately formed to the shape of the open space between the teeth. The work may be done on a shaper, in which case the cutting tool is reciprocated across the face of the blank, parallel to its axis, and is fed in gradually toward the center until the required depth has been reached. The tool is then raised to its original position, the gear blank is indexed, and the action is repeated until all the

spaces have been cut out, leaving teeth of the required form between them. It is far more common, however, to embody this principle in a milling operation (see Figures 121 and 123). In this case, a formed milling cutter of the required shape, like that shown in Figure 122, is used. The gear blank is mounted on an arbor, as already described, and the cutter is fed once across the face, parallel to the axis, leaving a finished surface behind it. The cutter is then returned to its original position, the blank is indexed, and the cut is repeated until the gear is done. The milling cutter, shown in Figures 116 and 122, is of the relieved type; that is, the sides of the cutting teeth retain the correct form as they fall away from the cutting edge. A cutter so relieved may be ground on the face and will still cut the correct shape. The deviation from correct work depends partly upon the accuracy of the "set-up," and partly upon the accuracy with which the milling cutter is made. Theoretically, there should be a cutter of a different shape for each number of teeth required for every pitch, or size. Practically, however, the true form of the tooth changes so little that for ordinary work eight cutters for each pitch may be used for everything from a twelve-toothed pinion to a rack. The commercial cutters on the market are the following:

No.	1	will	cut	wheels	from	135	teeth	to a rack	
"	2	"	"	"	"	55	"	" 134	teeth
"	3	"	"	"	"	35	"	" 54	"
"	4	"	"	"	"	26	"	" 34	"
"	5	"	"	"	"	21	"	" 25	"
"	6	"	"	"	"	17	"	" 20	"
"	7	"	"	"	"	14	"	" 16	"
"	8	"	"	"	"	12	"	" 13	"

For work requiring more accurate teeth, half numbers may be obtained:

No.	1½	will cut wheels from	80	teeth	to	134	teeth
"	2½	" " " "	42	"	"	54	"
"	3½	" " " "	30	"	"	34	"
"	4½	" " " "	23	"	"	25	"
"	5½	" " " "	19	"	"	20	"
"	6½	" " " "	15	and		16	"
"	7½	" " " "	13	teeth.			

If the holes in the blanks are straight and the hubs do not project beyond the face, a number of blanks may be fastened together on the arbor and cut at the same time (see Figure 125). Care must be taken to make sure that the sides of the blanks are truly parallel; otherwise, when the blanks are clamped together, they will spring the arbor and cause it to run out making it impossible to produce accurate teeth. Machines using formed milling cutters are often automatic, and several may be operated by one attendant. When stock gears are made in large quantities, the machines may be simplified if a separate one is used for each size and kind of gear, for such an arrangement permits of using a plain index wheel that has the same number of holes as there are teeth to be cut. With this arrangement, teeth may be cut at random around the wheel to avoid uneven heating. The cutting of spur gears by means of formed milling cutters is the cheapest method, and is accurate enough for all ordinary work.

Formed milling cutters are also widely used for cutting bevel gears, but are not so satisfactory with bevels as with spur gears. Since bevel-gear teeth taper down toward the apex of the pitch cone, the

sides of the cut between them can never be parallel (see Figure 116), and it is therefore impossible, with a formed cutter that has fixed curves, to give the correct shape to the tooth throughout its entire length. The practice is to use a cutter that is correct for the large end of the tooth, and to set the work so that the tooth is cut to the proper thickness on the pitch line at the small end. The tops of the teeth are then too thick at the small end, and they are filed off. The milling process is more satisfactory with narrow-faced bevel gears than with wide ones, as the deviation from the correct form is not so marked. Since the teeth approach one another, the cut between them must narrow down, and it is evident that but one side of the tooth space can be cut at a time; accordingly at least two cuts must be taken for each space, the two cuts matching up on the bottom. Figure 116 shows a milling cutter cutting the left-hand side of a bevel-gear tooth; the opposite cut on the other side of the groove has been made.

Template Principle.—The second, or template principle, is illustrated in Figure 117, which shows a small portion of a bevel gear with the teeth already cut. The letter o marks the apex of the pitch cone, toward which all the tooth elements, such as a—b and c—d center. A template, A, having a curved portion, e—f, of the correct form required for a tooth at the distance a′—o from the apex. If the line a′—o be held at o, and the other end be moved along the template to c′, it would follow the side of the required tooth, a—b—c—d. The principle is applied practically by having a shaper tool mounted in a frame,

which swings about the point o under the influence of the former, A, the point of the cutting tool moving backward and forward from a to b across the face of the gear on the line a′—o. A roller, B, on a swinging frame, follows the former from a′ to c′ and guides the tool in a series of cuts that will produce the surface required. According to this method, the bevel-gear blank is first gashed with grooves which rough out most of the stock, leaving the sides to be finished. The corresponding sides, x—x, of each tooth are finished, and a new former, curved in the opposite direction, is used to form the opposite sides, y—y, in a second series of cuts. This method is used mainly in connection with bevel gears, as shown, but may be used for cutting spur gears; the only difference, in the latter case, is that the successive strokes of the cutting tool, instead of centering on the point o, are parallel. In fact, a spur gear is a special case of a bevel gear, in which the point o has moved off toward infinity, and the pitch cone has become a cylinder. The cutting tool is made narrow enough to go through the opening between the teeth at the smallest point, and right- and left-hand cuts match up on the bottom, as in the milling operation illustrated in Figure 116.

The template method applied to bevel gearing is much more accurate than the formed-cutter method. The only errors possible are inaccuracies in the shape and setting of the former, and the inability of the tool to coincide exactly with the radial line to the apex. These inaccuracies are small, however, and teeth cut on this principle are very satisfactory.

Describing-Generating Principle.—The describing-generating principle duplicates mechanically the method of drawing the involute curve. This curve, which forms the basis of the sides of involute teeth, is the one traced by a point in a string which is unwrapped from a cylinder (see Figure 115). The circle corresponding to the cylinder is called the base circle. Suppose that the point of a shaper tool, a, is held against the side of a gear blank mounted on center, b, below it, and that it touches the gear at the top of the base circle. If the base circle of the gear blank is rolled to the right along a horizontal line, c—d, through the point of the tool, the tool will trace an involute curve, a—e, on the side of the gear. If, during this process, the shaper tool is given a reciprocating motion across the face of the gear, it will cut a true involute surface that may be used as one side of the tooth. In practice, the side of the tooth would be cut in the reverse direction, from e to a, but the principle is the same. By indexing the blank all around, the corresponding sides of each tooth may be similarly generated. By setting the blank over the thickness of a tooth and making the sidewise motion to the left instead of to the right, the opposite sides of the teeth may be formed. This method may be used for cutting either spur or bevel gears. In the case of spur gears, the strokes of the cutting point, a, will all be parallel. In the case of bevel gears, they will center down to a common point corresponding to o in Figure 117.

Form-Generating Principle.—The fourth principle —the form-generating—is based upon the fact that

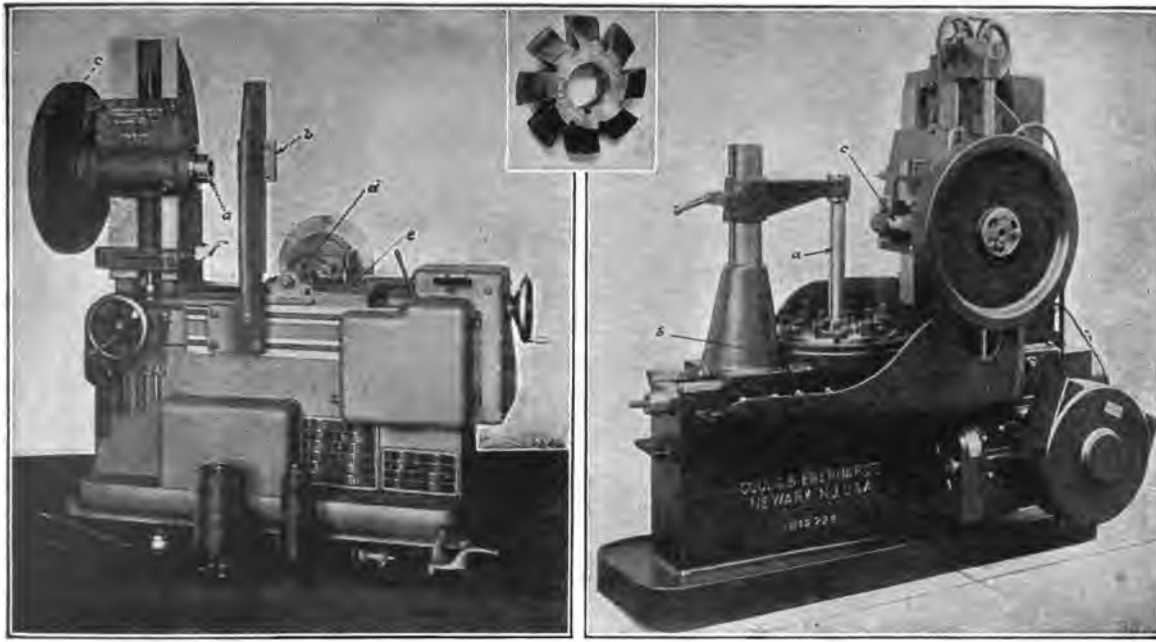
any gear in an interchangeable set will run with any other gear of the set. This is true no matter what the number of teeth may be, and applies to racks as well as to gears of any diameter. The operation of this principle may be reversed and utilized to make one gear form cut another. If one of the gears is of hardened tool steel, and has the edges along one side of the teeth sharp enough to act as cutting edges, that gear may reciprocate sidewise across the face of the other, the cutting gear and the blank being rotated, meantime, as if they were in mesh. The result of this action is that the teeth of the cutting gear forms grooves in the other which will conform exactly to the space between the teeth that a mating gear should have. This action is illustrated in Figure 119. The successive positions shown represent the position of the tooth, a, with reference to the work; the shaded portion, b, shows the material that would be cut out by one of the transverse passes of the cutting gear. The distance between the successive positions in the figure is, of course, far greater than it would be in actual practice. This principle is embodied in a Fellows gear-shaper, Figures 125 and 126, and may be used in cutting either spur or spiral teeth. In the former case, the gears have no rotation during the cutting stroke; in the latter instance, they are given a uniform rotation during the cutting action, which results in a spiral tooth instead of a straight one. This form-generating principle gives very accurate work. The operation known as hobbing, which will be described later, is based on this principle.

The cutting gear may have any convenient number of teeth, or may be part of a rack. The teeth of a rack are often used to do the forming, as the side of a rack tooth is a straight line, and therefore easier to originate. Figure 120 shows the generating principle applied in four ways. At A the rack is rolled past a plastic gear and the teeth are moulded by impression. At B the tool, T, to the right, has a straight cutting edge, which conforms to one side of a tooth in an imaginary rack. If this is made to travel to the right, as the rack did in A, and if at the same time it has a sidewise reciprocating motion, it will cut out the side of the tooth which it touches. If the cutting tool has two cutting edges, corresponding to the opposite sides of a tooth on the rack, as at T′, it will cut out both sides of the tooth space. Instead of a reciprocating cutter, a milling cutter may be used, as at C, the side of the cutter conforming to the imaginary tooth rack and duplicating in every way the action of the shaper cutter, T, in B. In D the side of an emery wheel is substituted for the milling cutter of C; the action is the same in both cases. Of these four means, the first, or impression, method is of course impracticable; it is mentioned only to help to illustrate the principle. The shaping and milling methods, shown at B and C, are widely used. The grinding method, shown at D, is used to true up the surfaces of gears, which have been cut by one of the previous methods, and then hardened; it is the most accurate of all.

Spur-Gear-Cutter.—Only a few of the typical gear-cutting machines can be shown, as there are literally

scores of designs. The most generally used is the automatic spur-gear-cutter, similar to those shown in Figures 121 and 123. In the machine shown in Figure 121, the gear blanks are mounted on a horizontal arbor, which is carried in the spindle, a, and is provided with an adjustable outboard support, b, in order that the greatest possible firmness may be given to the work. This arbor is capable of rotation, but is under the control of a large and very accurately divided index wheel, in the casing c, which controls the spacing of the cut around the rim. A formed milling cutter, like that shown in Figure 122, is carried on a spindle, d, and is given a feed across the face of the gear. As each cut is completed the carriage, e, is returned, the work is indexed to the next position, and the next cut is made. All the motions of the machine are automatic; the speed of indexing is independent of the rate of feed and speed of the cutter, and the indexing is done as rapidly as it is possible to do it without causing shock. The feed mechanism of the cutter is disengaged during the indexing, and becomes operative only on its completion. Figure 123 shows the position of the cutter and the work reversed; the gear blanks are held on the vertical arbor, a, carried by a saddle, b, on the bed of the machine. The index wheel is inside the saddle. The cutter spindle, c, is carried by the upright, and has a vertical travel instead of a horizontal one. The principles of action are not altered by this change in arrangement.

Machine Embodying Template Principle.—Figure 124 shows a machine embodying the template prin-



FIGS. 121 AND 123. AUTOMATIC SPUR GEAR CUTTING MACHINE
Brown & Sharpe Mfg. Co., and Gould & Eberhardt.

 FIG. 122 (INSERT). FORMED MILLING CUTTER FOR CUTTING GEAR TEETH

ciple. The upright portion of this machine is a specialized form of the vertical slotter described on page 000. In fact, it will be seen that the slotter illustrated in Figure 97 might be rigged up to perform the functions of this tool. The column is mounted on a long base plate, a, and may be moved in and out to accommodate different diameters of gears. The gear blank is supported on an arbor, b, on a rotating table, which is indexed by a worm and a worm wheel operated through change gears by an electric motor provided for that purpose. The machine is large enough to swing work forty feet in diameter. The templates for shaping the tooth outline are mounted in brackets, c,c, on the tool head on either side of the tool post. The tool post is pressed toward the right- or left-hand former by a spring, as may be required, and is provided with a feeding mechanism for moving it outward. It is thus used to reproduce the outline of the template and to form each side of a space between two teeth. This type of machine is used for coarse-pitch gears that are too large to be cut by a formed tool. It has the advantage over the formed cutter process of being comparatively simple in operation and adaptable to special work; gears of this size are never made in quantity.

Fellows Gear-Shaper.—The Fellows gear-shaper, shown in Figures 125 and 126, is a successful application of the form-generating method. Figure 125 shows three gear blanks mounted on the work spindle. The cutter has the form of a complete gear, and is carried on the end of a reciprocating vertical ram or slide, a, in the saddle, b. The saddle is adjustable

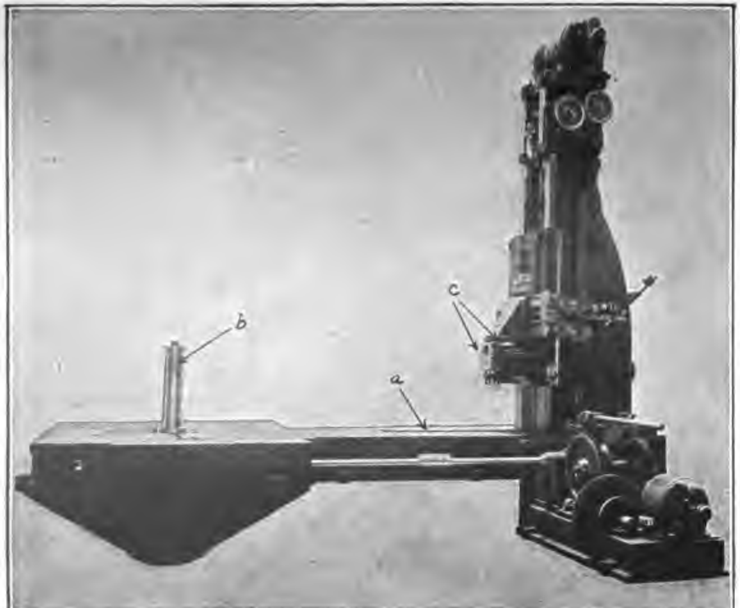


FIG. 124. GEAR PLANER USING THE TEMPLATE PRINCIPLE
Newton Machine Tool Works.

FIG. 125. GEAR SHAPER
Fellows Gear Shaper Co.

sidewise to accommodate work of different diameter, and the stroke of the ram is adjustable to suit different widths of face on the work to be cut. The action of the machine is as follows:

The saddle with the cutter is withdrawn from the work spindle, and the blanks are set in place. Without rotating either the cutter or the work, the head is fed inward toward the center of the blank. This feed is continued until the cutter has cut its way into the blank to the proper depth. The inward feed is then stopped, and the cutting tool and the blanks are rotated slowly at the same pitch velocity. The rotation takes place intermittently at the end of each stroke of the cutter. As this action is continued, the cutter will gradually generate the teeth around the surface of the blank until the gear is finished. An adjustable stop, c, is shown on the side of the head, which is set down against the side of the gear or the supporting device and locked in position. The stop takes the reaction of the cut, and relieves the driving mechanism of any tendency to spring. The cutting stroke is usually upwards, so that it forms a draw cut —the thrust taken up by the stop. The cutter may be reversed and work on the downward stroke when it is necessary to plane into a recess, as in automobile transmission gears. This type of machine, which is used for medium-sized gears, produces very accurate work. The sides of the cutter are relieved so that the tool may be ground on its upper face without losing the correct shape, and the cutter is trued up by grinding after it is hardened, by the process illustrated in C, Figure 120.

Hobbing Machines.—The form-generating principle may be used for machines of the milling type as well as for those of the shaper type. A case in point is the hobbing process. Figure 127 shows

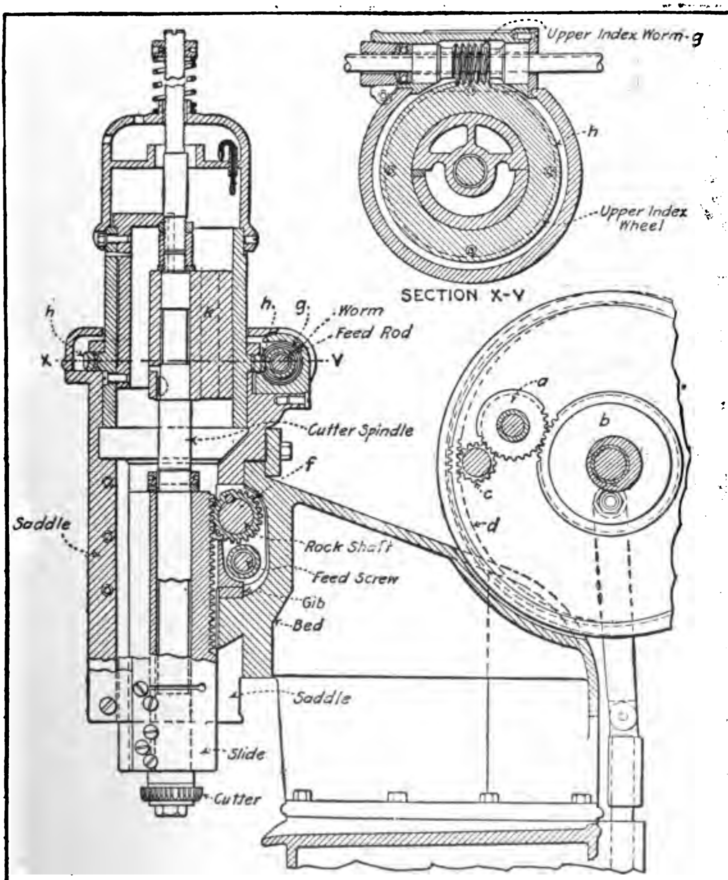


FIG. 126. SECTION OF GEAR SHAPER HEAD
Fellows Gear Shaper Co.

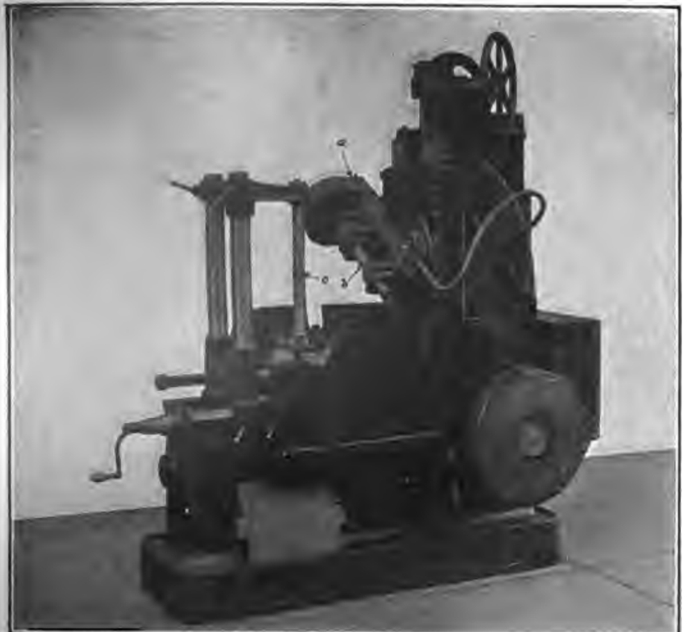


FIG. 127. AUTOMATIC HOBBING MACHINE FOR SPUR, HELICAL, AND WORM GEARS
Gould & Eberhardt.

FIG. 128. GEAR-SHAPER SLIDE FOR CUTTING HELICAL GEARS
Fellows Gear Shaper Co.

an automatic hobbing machine that may be used for cutting either spur, helical or worm gears, according to the angle at which the cutter head, a, is set. The cutting tool used is a "hob," (see a, Figure 99), a special type of formed milling cutter, in which the teeth are shaped and relieved, as in Figure 122, but are arranged in a helix, like a screw thread, instead of in a circle. Every one has noticed how a screw thread appears to travel along its axis as the screw is revolved. If the hob is mounted on the spindle, b, and the axis is tipped up at an angle equal to the helix angle, the cutting motion of the edges will be parallel to the axis of a gear blank mounted on the arbor, c; the action of the edges will have the same effect as that of the milling cutter in C, Figure 120, as it moves past the face of the blank. In operation, the gear blanks mounted on the arbor, are first fed inward toward the cutting tool, and are rotated by a power feed meantime, in order that they may have the rolling action required. When the proper depth of cut is reached, the cutting head is given a gradual downward feed across the face of the gears until the work is completed. In some respects this type of machine is better than the ordinary one shown in Figures 121 and 123, since a greater number of teeth are cutting at once, but absolute rigidity is more important in this type and the motions are more difficult to control.

Cutting Helical Gears.—Helical gears may be cut by either the shaping or the milling process. The Fellows gear-shaper, shown in Figures 125 and 126, may be used to cut them. If the Fellows machine is

used, the cylindrical guide, k, in Figure 126, is given an additional rotary motion by means of the helical cam surface, a, Figure 128, which has the same lead as the helix of the cutter, b, at the other end of the shaft, c. The camming action of the surface, a, on a fixed pin, not shown, gives the cutter the correct helical motion required. The hobbing machine, Figure 127, may be used to cut helical gears; the head may be set around so that the teeth of the hob will move past the pitch surface of the gear blanks at the required helical angle, and the rotary feed of the blanks may be suitably adjusted. In other respects, the action of the machine is the same as for cutting straight teeth. If the axis of the cutting hob is set horizontal, the machine may be used to cut a worm gear.

Cutting Bevel Gears.—Figure 129 shows a machine that is used to cut bevel gears according to the formed-cutter method. In many respects it is like the machine shown in Figure 121, but the slide, a, Figure 129, carrying the cutters (not shown) is in this case provided with an angular adjustment, b, in the vertical plane, to give a feed along the pitch cone. The action of the machine is similar in other respects to the spur-gear cutter—if the saddle is dropped to a horizontal position, it may be used for spurs.

Figure 130 shows a bevel-gear cutting machine that embodies an application of the former, or template, principle illustrated in Figure 117. The blank is mounted on a horizontal indexing arbor, a. The cutting tool, b, is carried in a shaper head sliding on a carriage, c, which has a horizontal angular adjust-

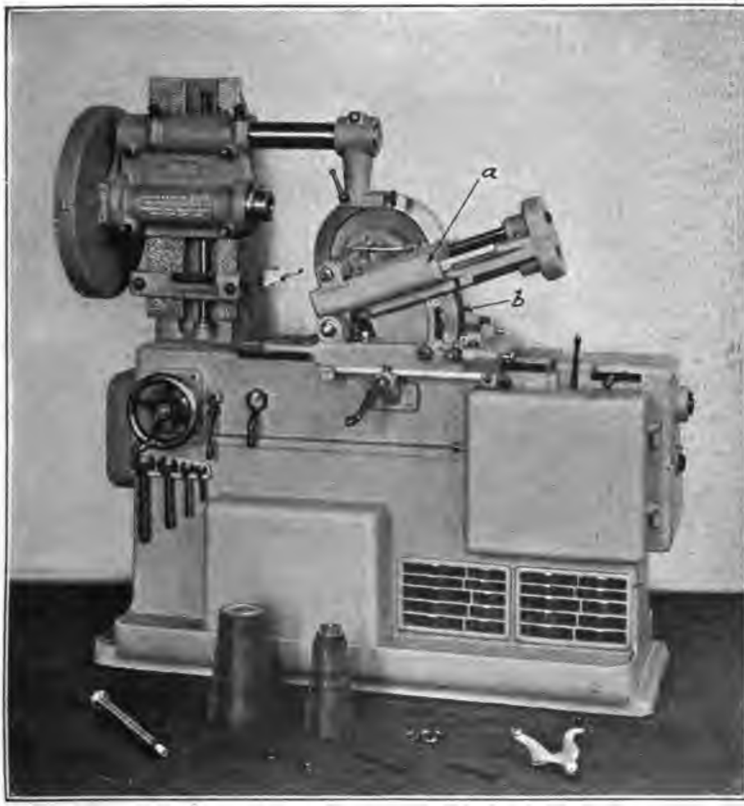


FIG. 129. AUTOMATIC BEVEL-GEAR MILLING MACHINE
Brown & Sharpe Mfg. Co.

ment so that it may be set parallel to the side of the theoretical pitch cone of the bevel gear to be cut. In the view shown, it is seen nearly "end on," and the stroke of the tool-carrying head is forward along the sliding surface, c. The path of the cutting tool, b, as it is slowly fed in toward the center of the blank

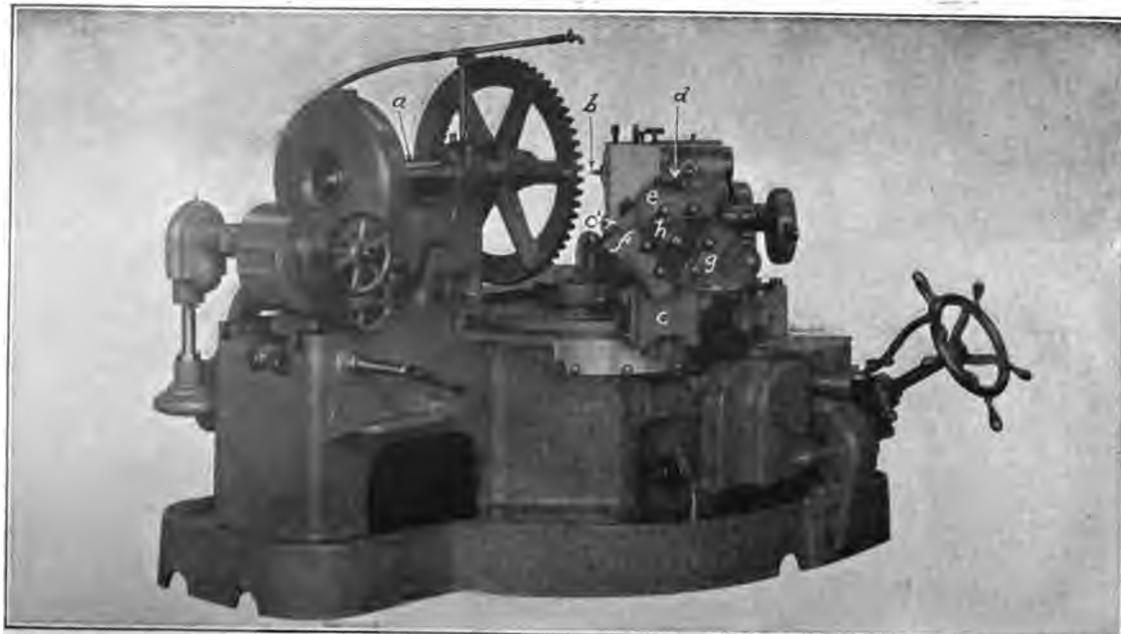


FIG. 130. AUTOMATIC BEVEL-GEAR PLANER—24-INCH SINGLE-TOOL FORMER TYPE

Brown & Sharpe Mfg. Co.

between each cutting stroke, is controlled by the roller, d, corresponding to the one, B, shown in Figure 117. Three former plates, e, f, g, are mounted on the triangular plate, h. The first one, e, on which the roller now rests, is straight, and is used for a plain roughing cut once around, which removes most of the stock between the teeth. The plate, h, is then rotated one-third of a turn, and the former, f, is used to finish one side of the teeth. When this has been done around the blank, the third former, g, is used to finish the opposite side of the teeth.

Machine Embodying Form-Generating Principle.—The form-generating principle is used in the machine shown in Figure 131, which is built by the same firm as the one that builds the machine just described. If the height of the pitch cone of a bevel gear is shortened, the gear grows flatter until the limit is reached in one of zero height, in which the teeth are ranged around in a circle on a pitch surface that is a plane. Such a gear, called a crown gear, bears the same relation to bevel gears that the rack does to spur gears; and the teeth, like those of a rack, have straight sides. Just as the cutter, T, in B, Figure 120, replacing the side of an imaginary rack tooth, may be used to generate a spur tooth, so a straight-sided cutting tool, replacing the side of a crown gear tooth, may, when properly rolled in relation to a bevel gear blank, be used to cut the proper tooth form. The gear to be cut is shown at a. Since there are two cutters, both sides of a tooth are finished at once. The upper cutter, b, is shown just clear of the work; the lower one is hidden. Those sectors of the

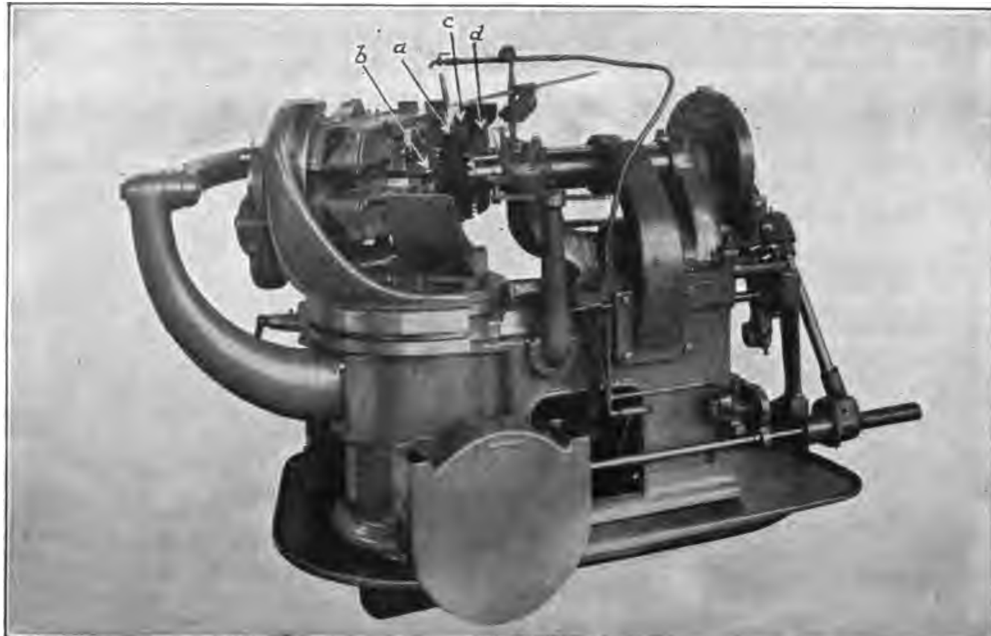


FIG. 131. AUTOMATIC BEVEL-GEAR PLANER—18-INCH TWO-TOOL GENERATING TYPE
Gleason Works.

crown gear and the master gear which are controlling the motion are seen at c and d.

The same firm has developed a machine for generating with a milling cutter a bevel gear that corresponds to the helical spur gear. In this gear the teeth are curved on the arc of a circle.

There are so many types of gear-cutting machines that it is impossible to consider all of them here; enough have been shown, however, to illustrate the more general principles involved.

CHAPTER XX

SCREW-THREAD-CUTTING

Early Methods of Cutting Screw Threads.—Screw-thread-cutting, like gear-cutting, is one of the fundamental operations found in every machine shop, however crude. The early screws were large, and made of wood, because such screws could be "chased" by hand on the rough speed lathes then used. The first metal screws were formed by means of hardened dies of the crudest kind, without cutting edges, which were turned and forced onto the bar to be threaded. They were, of course, wretchedly inaccurate, and many attempts were made to originate threads with some pretense to accuracy. Many of these early attempts were very ingenious; in one instance, two wires side by side were wound around the bar and soldered to it. One of them was then removed, leaving a space between the coils of the other, and forming a screw thread.

Another method was to chase the thread with a cutting tool, which was fed forward by a knife-like edge held against the work at the required thread angle and allowed to run freely, carrying the cutting tool with it as the work was revolved. This method was better, and it was the one used by Maudslay in generating the lead-screw threads for his first lathes. The invention of the slide-rest soon led to the development of the lead screw and the screw-cutting

lathe. As pointed out elsewhere, Maudslay at first used a different lead screw for each size of thread, but he soon developed the combination of a single lead-screw with change gears to vary its speed in relation to the work; this is used today.

Standardization of Screw Threads.—There is no detail in machine construction in which standardization is more essential than in connection with screw threads. We are so used to standard practice in this respect that the modern mechanic does not realize the chaos that existed in the early machine shops. Every nut had to be fitted to its respective bolt, and both were marked in order that they might be identified if they were taken apart. The first attempt at standardization was made by Maudslay, who settled upon a set of standard taps and dies for use in his own shop. Joseph Clement, a mechanic who worked for Maudslay, took up his work, standardized it still further, and began manufacturing it for the market. Joseph Whitworth, who worked for both Maudslay and Clement, standardized the screw-thread practice of England, and in 1841 brought out what is still known as the "Whitworth thread."

Types of Screw Threads.—Since screw threads are used for a wide variety of purposes, it is not possible to standardize them completely, but standardization has been made to the extent of reducing them to a few well-known types, which are differentiated partly by their use and partly by their historical origin.

The simplest thread is the V-thread, a cross-section of which is shown at A, in Figure 132. This is formed by straight sides, which are on an angle of 60 degrees

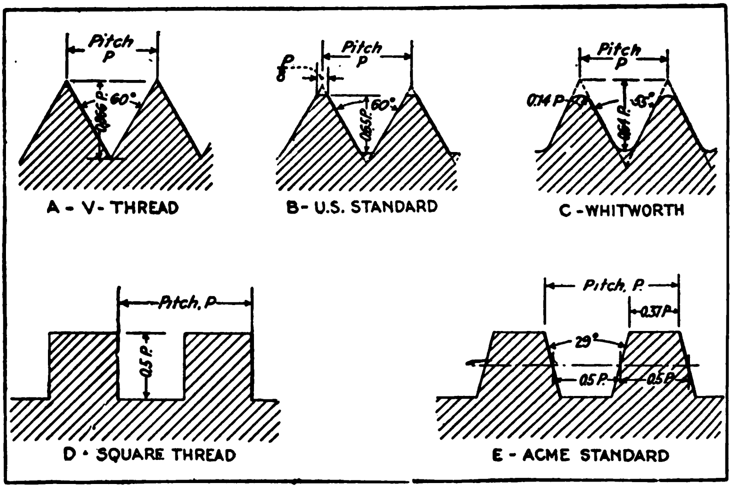


FIG. 132. SECTIONS OF STANDARD SCREW THREADS

to each other, and which have sharp corners at top and bottom. This thread is the simplest to make, but it has many disadvantages. The sharp point on the outer end of the thread is easily bruised, while the sharp corner at the root of the thread weakens the bolt greatly, and is difficult to maintain on account of the wearing of the point of the tool that makes the cut. This form, however, is well adapted to the making of pressure-tight joints and in slightly modified form, is the basis of the Briggs thread, which is standard for pipes and pipe fittings. This is almost its only commercial use.

The United States standard thread, B, is similar to the V-thread, except that the top and the bottom are flattened for a distance equal to one-eighth of the pitch. The depth is therefore three-quarters that of the cor-

responding V-thread. This standard was developed by William Sellers, of Philadelphia, in 1864, and is the one most widely used in the United States. It is less liable to injury than the V-thread, and is much stronger. The tools for cutting it are quite as easily made, and much more easily maintained.

The standard thread used in England is the Whitworth thread, C, the sides of which have an angle of 55 degrees instead of 60; the top and bottom are rounded instead of flat. In some respects this thread is better than the United States standard, as it has no sharp corners and wears well; it is not, however, so easy to originate. The metric screw thread used on the continent of Europe was adopted in 1898 by an international congress which studied all the standards then in existence. This thread is similar to the United States standard, but a slight clearance is permitted, which is obtained by rounding the corner at the root of the thread.

All of these standards have not only a specified cross-section, but a definite number of threads per inch for each size of bolt. The United States standard has larger threads for small screws than has been found the best in practice. An additional standard has therefore sprung up, known as the S. A. E. standard, for the smaller sizes, which conforms to the shape of the United States thread, but contains more threads per inch.

In all these standards the angle between the sides of the thread is 55 or 60 degrees. An angle as steep as this produces a considerable side thrust on the nut, which increases the friction. When the threads

are used for holding-down purposes—as in the case of bolts and nuts, this friction is an advantage. When the thread is used to transmit running motion, friction is a detriment; hence, square threads, as shown in D, were developed for this purpose. In these, the space and the tooth have the same thickness. Such threads are little more than half as strong as United States threads, and cannot be cut in dies.

For transmitting motion intermittently—as in the traversing of a lathe carriage by the lead-screw—the nut is made in halves, to be clamped on the thread when desired. For such a purpose, the square thread is difficult to enter, and has no take-up for wear. To overcome these difficulties, the Acme Standard thread, shown at E, is now generally used. The angle between the sides of this thread is 29 degrees, and the flat place at the top is about one-third of the pitch. The widths of the thread and the space are equal at a point midway of their height. This thread is a compromise between the United States and the square thread, and is generally used for lead screws and other forms of working screw. It is stronger than the square thread, allows take-up for wear, is easily clamped by a split nut, and may be cut by ordinary taps and dies.

Other forms of threads are used for special purposes, but need not be considered here.

Cutting Screw Threads.—Modern methods of cutting screw threads are: first, by means of taps and dies, operated by hand or in a machine; second, by means of lathe and lead screw; third, by cam control in automatic turret lathes; and fourth, by milling.

For thread-cutting, the first method is used more than any other. Hand taps and dies are described and illustrated in Chapter XII. For light special work and for rough outside work—such as construction work, country blacksmithing, etc.—these are used in holders provided with two handles. For the smaller sizes of screw threads, the taps must be solid; they are practically like those illustrated in Figures 42 and 43.

In the larger sizes of taps, which are used with machines, the cost of making the entire tool of tool steel would be prohibitive, so the cutters are made separate and inserted in the body. This method has a further advantage in that the cutters may be set out to allow for wear. A great variety of taps and dies has been developed for use on the various machine tools that do threading work.

Bolt-Threading Machines.—The machines most used for this purpose are the drill press and the turret lathe, both hand and automatic types. Drill presses that are used for this work are equipped with change-gear feeds to give the spindle a lead corresponding to that of the thread to be cut. The holder which carries the tap may be equipped with a friction drive which slips if the tap sticks or strikes the bottom of the hole. Drill presses are also fitted with an automatic reverse on the drive, which may be set for a certain depth, so that when the tap has reached this point the spindle is reversed and the tap is backed out. The drill press is generally used for tapping, or threading, rough holes, such as those used for stud bolts in valves, fittings, and general machinery.

Studs or bolts, when produced in quantities, are threaded in a bolt-threading machine, such as that shown in Figure 133, which is specially designed for this purpose. Machines of this character have a power-driven spindle that carries the threading die, a; the bolt, b, to be threaded, is carried in a suitable holder, c, mounted on the slide, d, which is free to move in and out. The die head, a, which does the threading, is opened and closed by a trip rod, e, provided with two adjustable stops. One of these stops, operated by the in-and-out-motion of the slide, is set to open the die when the bolt has been threaded the required length; thus it is possible to withdraw the work quickly without reversing the machine. When the carriage has moved backward, the other stop closes the head and is ready to cut the next bolt.

Opening Die Heads.—There are many types of opening die heads used on machines of this style and in turret lathes. One of these is shown in Figure 134. The sliding cutters, or chasers, a, of carbon or high-speed steel, are clearly shown on the face of the die. They are held in correct register with each other by a spline, or key, b, on the side. The first few threads of the cutters are ground away at c in order that the work of cutting may be distributed over several teeth instead of being concentrated on the first tooth, as would be the case if the full section were retained. The middle section of the die, d, carries on the side next the cutters four projecting spiral cams, e, one for each cutter, which engage corresponding notches, f, in the rear edge of the cutters. When the handle, g, is pulled down, these pro-

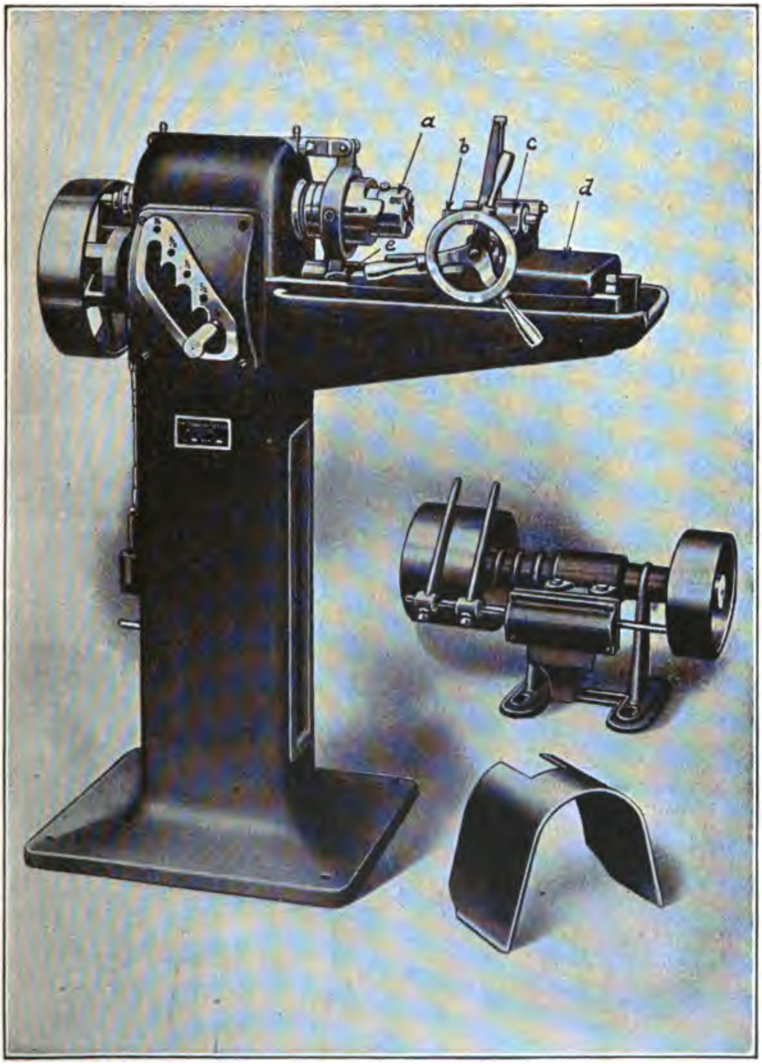
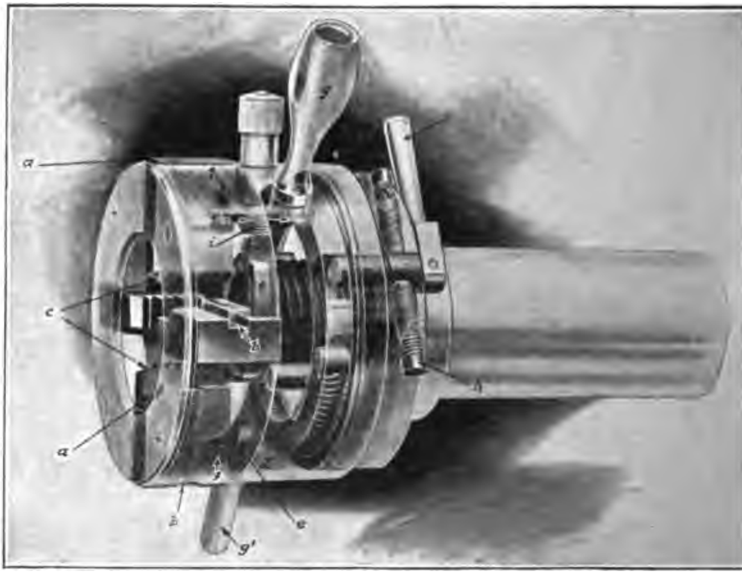
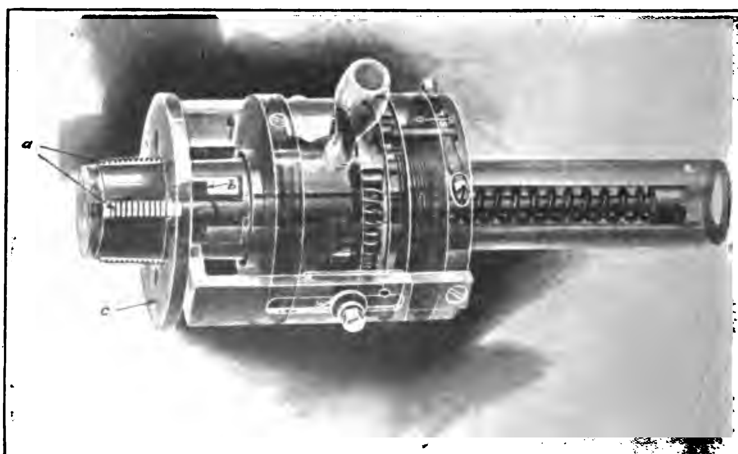


FIG. 133. BOLT-THREADING MACHINE





FIGS. 134 AND 135. COLLAPSING DIE HEAD AND COLLAPSING TAP
Geometric Tool Co.

jections cam the cutters into the working position. The die opens automatically by simply stopping the forward travel of the die when the desired length of thread has been cut. This throws the cutters back so that the die head may be withdrawn without having to be unscrewed from the work.

The cutters may be thrown in again by using the handle or by having a steel tripping-piece strike the pin, g′, opposite. They may be adjusted to cut tight or loose threads by means of the adjusting screws, h′, the amount of adjustment is read directly on the micrometer scale, i, on the side of the head. Roughing and finishing cuts may be taken by throwing the lever, j, forward. This moves the cutters out 0.01 inch. The return of the lever to its backward position closes the cutters and locks them in position for the finishing cut. There is a clear hole through the center of the die head and the shank, somewhat larger than the maximum diameter to be threaded, which permits threading any length required.

Figure 135 shows a collapsing tap corresponding in size to the die, Figure 134. In this case, the cutters, a, are held out in working position by the wedge, b. When the proper depth has been reached, the face of the work pushes back the contact plate, c, and releases a trip, so that the spring withdraws the wedge and allows the cutters to disappear into the holder. There are a great many collapsing taps and dies, but those shown are sufficient in number to illustrate the principle involved.

Pipe-Threading Machine.—Figure 136 shows a machine for threading pipe. In this machine the posi-

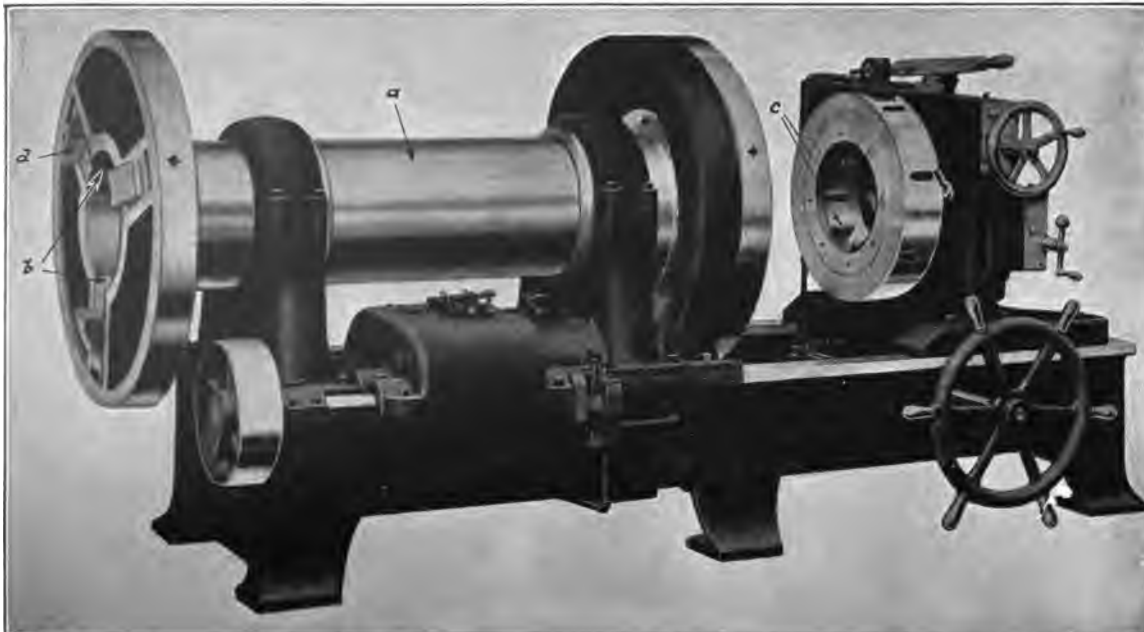


FIG. 136. PIPE THREADING MACHINE
Bignall & Keeler Machine Works.

tions of the work and the die are reversed from those shown in Figure 133. Pipe comes in lengths of 20 feet or more, and is large in diameter. The spindle, a, which is used to carry the work, is of cast iron, long, hollow, and large enough to take in the maximum size to which the machine is adapted. Clamping jaws, b, provided at each end to be as far apart as possible, give the work a firm support and center it with the dies. The cutters, c, shown inside the die head, are arranged so that they will collapse into the head when the thread is completed. Special devices are provided for holding short lengths of pipe—such as nipples—and extra steps, similar to those shown at d on the rear clamping jaws, are used to hold pipe flanges for threading.

Thread-Cutting on Lathes.—While nearly all commercial thread-cutting is done in dies, special threads wanted singly or in small numbers would be cut on the engine lathe. Long and accurate threads, also, such as those required for the various machine tool feeds—shown in the foregoing pages—are cut on lathes. The operation is a skilful one, and the degree of accuracy obtainable is in a large measure controlled by the precision of the lead screw that is used. Master lead screws used by tool-builders for cutting their own product, are very expensive and have to be handled with great care.

The work is mounted on the lathe centers, and a cutting tool that has a cross-section of the groove between the threads, is mounted in the tool post. The proper change gearing is used which will give the lead required—or distance traveled longitudinally for

each turn of the screw to be cut—and a light cut with the point of the tool is made along the surface to be threaded. The tool is then withdrawn from the work, returned to its starting position, and fed in a little deeper for the second cut. This process is repeated, and each time the tool is fed in a little more, until the proper depth has been reached. Figure 35 shows a tool-holder with a separate formed cutter that has the required shape. One disadvantage of this method is that the greatest wear comes on the point of the tool, which can least afford to bear it.

Figure 137 shows a special threading tool which has been developed to overcome this difficulty, and which simplifies the making of the successive cuts. It shows an application of the turret principle, but it is used on the carriage of a standard engine lathe in place of the regular tool post. It consists of a cutter with ten cutting edges, which are used in succession. After the tool has been set to cut the proper size, the first of these cutting edges, a', is used to make the first cut. The handle is then operated which indexes the second cutting edge, a^2, into position. This makes a second and slightly deeper cut.

All the cutting edges are brought into action successively, each one deepens the cut, and the last one brings it to the correct size. The condition of the work after cuts 1, 5, and 10 have been made, is shown. The first cutting edges have broad blunt points—only the last one or two need have sharp points, for the cut is practically completed before they do their work. These last edges therefore retain their shape for a long time. The sides of the cutter are made on the

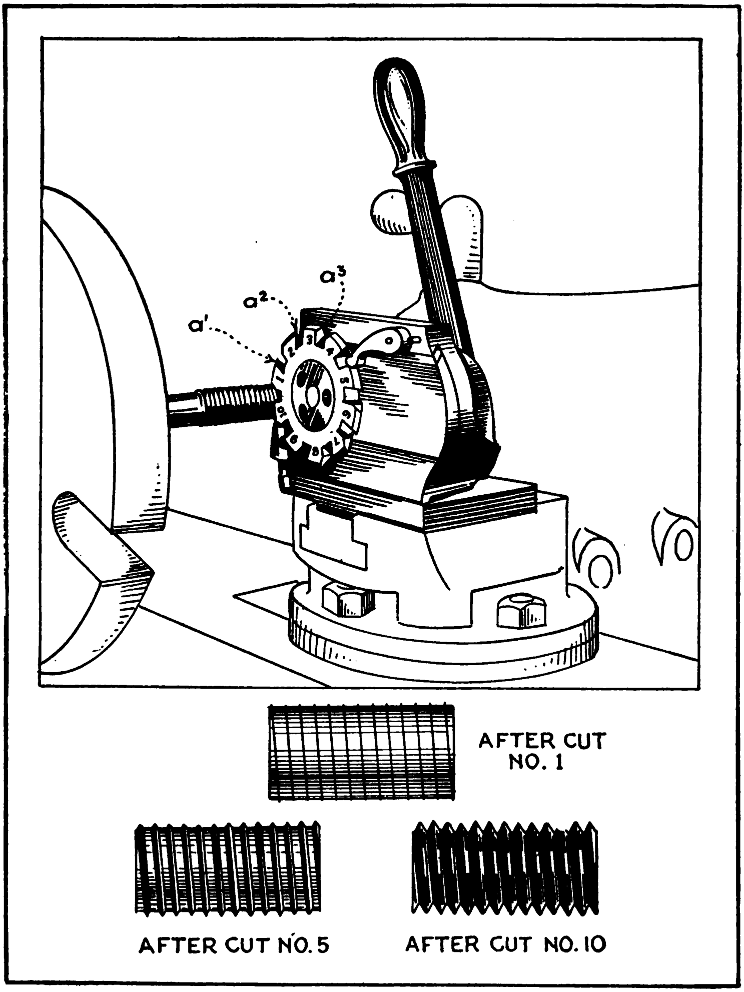


FIG. 137. INDEXING THREADING TOOL
Rivett Lathe & Grinder Co.

formed principle, so that the various edges may be ground on the face and still retain their correct shape.

Milling Screw Threads.—In Figure 111 is shown a standard milling machine set up to mill a short screw thread. For milling screw threads special machines have been developed which are also very useful for cutting long threads, especially those that are of large diameter. Figure 138 shows a machine of this character. The work is mounted on the spindles, as in an ordinary lathe, but revolves only for the feed, and a milling cutter is carried on a suitable spindle in the traveling carriage. The cutting and feeding motions of the ordinary lathe are reversed, as the cutting motion is given to the milling cutter, which is in the head, a, next the work, and not visible in the picture. It has a travel lengthwise corresponding to the lead of the screw to be cut.

The carriage and head, a, with the cutter start at one end and are gradually fed lengthwise while the work is given a slow rotary feed. The traveling head carries a rest, which takes the thrust of the milling cutter. The spindle that carries the cutter has an adjustment in the vertical plane, so that the cutter may be tipped to the angle corresponding with that of the thread. A special milling cutter is used, the teeth of which are staggered. One tooth is left full for the purpose of gauging. This type of machine is used for lead- and feed-screws, worms, spiral gears, and high grade, solid-end helical springs. The quality of work obtainable by this method is very satisfactory, and, as the cutting action is continuous, the method is efficient for manufacturing purposes.

FIG. 138. THREAD MILLING MACHINE
Pratt & Whitney Co.

FIG. 139. THREAD ROLLING MACHINE
E. W. Bliss Co.

Rolling Threads.—For certain uses, threads are sometimes rolled instead of cut on solid stock. This process can be employed only for small work, such as the threading of bicycle spokes. It has certain advantages. With cut threads, the diameter of the stock used has to be the outside diameter of the thread. With a rolled thread, it need be only about the mean diameter of the thread, since the material that is rolled out at the root of the thread goes up to form the top. When the thread, as in a bicycle spoke, occupies only a short length at the end, this advantage may mean a considerable saving of material. However, threads formed in this way can never be theoretically correct, and the process weakens the material so that a rolled thread is not so strong as a cut thread of the same size.

Figure 139 shows a machine for rolling threads on the tops of cans. Here the method is practical and very economical, since accuracy in form is not required and the material is too thin to be cut. Several of the threaded tops are shown in the foreground. The threading dies, a, are circular, and the grooves that form the threads are on the circumference of the roller. The top is inserted sidewise between the rolls and finished almost instantly, in a few turns.

CHAPTER XXI

GRINDING, AND GRINDING MACHINERY

Development of the Grinding Process.—The field of grinding in machine-shop practice has been changing steadily for the last forty years. Formerly the process was used only for sharpening the edges of tools that had been hardened. This sharpening was done by means of soft grinding wheels which were made of natural stone, and which of necessity ran at a comparatively slow speed. About 1873, Mr. F. B. Norton, of Worcester, Mass., began experimenting on vitrified emery wheels; he put them on the market a few years later. Since that time, other forms of abrasive have been developed, and their use has steadily increased. The first use was in connection with rough work on simple grinding stands, to remove sprues, fins, and so on. From this phase, grinding jumped to the other extreme and became an accurate tool-room process. And now it is being used more and more for economical precision work on a manufacturing basis. In the last of these uses, it is ordinarily a finishing operation on pieces that have been machined with edged tools, of either the lathe or the milling type.

Special Advantages.—Grinding has several advantages possessed by no other cutting process. It is

the only method of machining steel after it has been hardened. Hardening and tempering almost invariably distort the pieces treated. When accurate shapes are required, as, for instance, in milling cutters, the pieces are machined slightly large, to allow for this distortion, and are then ground accurately to size in a finishing process after the heat treatment. Another advantage of the grinding process is that it works with the lightest known tool pressure, and can be used on delicate pieces that would have a tendency to spring away from the cutting edge of an ordinary tool. This advantage is of particular value in the grinding of long spindles, shafts, and so on.

Still another advantage is that the scale on castings and forgings, which destroys the cutting edge of an ordinary tool, does not interfere with grinding, and, whereas one-eighth inch is the usual allowance for finish with an edged tool, one sixty-fourth or one thirty-second of an inch, only, need be allowed for grinding—just enough to insure that the surface will be properly cleaned up. A disadvantage for accurate sliding surfaces in machine tools is the fact that such surfaces, when ground, may retain some of the emery and therefore cut each other. For this reason, grinding is not used in certain places where otherwise it would be of great advantage.

Grinding Abrasives.—Modern abrasives are of two kinds, natural and artificial. The natural abrasives are emery and corundum. Emery is a mineral, and a mixture of aluminum oxide and iron oxide in a ratio of about 60 per cent to 40 per cent. Corundum is a purified form of emery, with from 80 to 85 per cent

of aluminum oxide. The iron oxide present in these two materials is undesirable, and has no abrasive quality. Because of this, emery in particular is little used on automatic grinding machines at the present time.

The artificial abrasives are the following: carborundum, which is carbide of silicon made in the electric furnace from coke and sand, with salt and sawdust added to facilitate the reducing process; alundum, which is the trade name for a material consisting chiefly of oxide of aluminum, made from bauxite, a clay mined in Arkansas, and similar in chemical composition to the ruby and the sapphire; and crystolon, which is carbide of silicon, and which, like carborundum, is made from coke, sand, sawdust, and salt. Unlike alundum, crystolon has no counterpart in nature. It is most efficient when used on materials of low tensile strength, such as cast iron, brass, bronze, and aluminum. Aloxite, carbolite, and carbondite are recent materials, and are compounds of aluminum or silicon. All the artificial abrasives are made by fusing the raw materials at high temperatures in an electric furnace.

The natural abrasives are tougher than the artificial, but not nearly so hard. The shape and form of fracture of the abrasive particles are of importance, as well as their hardness. The diamond is the hardest substance known, but a grinding wheel made up of smooth, round diamonds would be of little use for cutting purposes. One of the great advantages of the artificial abrasives is that they break with a clean crystalline fracture which gives the particles

sharp cutting edges. When the steel dust produced by these wheels is examined under a microscope, it is found to consist of small, curled chips, which are similar to the large ones produced by an ordinary steel cutting tool.

Grinding Wheels.—A grinding wheel is practically a milling cutter with an infinite number of very small cutting edges. The abrasive used in grinding wheels is ground, screened through sieves, and graded according to the number of the finest meshed screen through which it will pass. For instance, a 36-grain wheel contains abrasive which passes through a 36-mesh screen.

The bond, or adhesive substance that binds the abrasive together, is usually composed of clay, silicate of soda, or shellac. Rubber, celluloid, or an oxidizing oil are also employed in some instances. Four types of bonded wheels are used, known as vitrified, silicate, elastic, or vulcanite—according to the process of their manufacture and the nature of the bond used—and finally, disc wheels. In vitrified wheels the bond is a mineral and clay mixture fused into a porcelain. These wheels are the most commonly used today, as they are not affected by heat, cold, water, oils, or acids. They are porous, and free from hard and soft spots. Their porous texture allows the particles of abrasives to be torn out readily in the grinding process, and the wheel does not clog up so easily with the material being worked upon. On the other hand, a vitrified wheel is not so strong as an elastic wheel and is more easily broken. Consequently the vitrified process cannot be used for thin

wheels, and it is not advisable to attempt very heavy side cuts with them.

Silicate wheels derive their name from the silicate of soda which constitutes the bond. These are known also as semi-vitrified wheels. They cut smoothly and with little heat; and they are used for grinding tools, when the temper must not be drawn. Their grade is dependable for the process of manufacture and can be easily controlled; they may be made in large sizes. Vitrified wheels are rarely made above 36 inches in diameter, while silicate wheels can be obtained up to 60 inches. In elastic wheels, shellac forms the bond, and in vulcanite wheels, rubber. The elastic wheels are strong, and consequently very thin wheels may be made which are not only elastic but which have smooth-cutting qualities; they can be used for deep side cuts. The disc wheel is wholly different; it consists of an accurately balanced steel disc on which is cemented a cloth or paper impregnated with powdered abrasive of the grain or fineness required.

Grading.—The nature of the bond of the grinding wheel determines how strongly the particles of abrasives will be held together—a question of great importance in grinding practice. Wheels from which the abrasive is readily torn are known as soft-grade wheels, and those which retain the grit strongly are called hard-grade wheels. The word "grain" in connection with grinding wheels refers to the size of the particles of abrasive; the word "grade" refers to the hardness or softness of the bond. The former is given in numbers and the latter usually by letter

for vitrified and silicate wheels. For the grades of elastic wheels, numbers are usually used.

Selection of Wheels.—The following elements must be considered in selecting the proper grinding wheel for any given work: material to be ground, degree of accuracy required, quality of finish required, size and shape of the work, whether it is to be ground wet or dry, whether the work calls for external, internal, or surface grinding, and the speed of the work, the rapidity of the side traverse speed, and the depth of the cut. It is apparent, then, that no specific rules can be given in regard to the selection of grinding wheels. In general, corundum and alundum wheels are most efficient for hard and soft steel, and carborundum and crystolon for cast and chilled iron. Soft bonded wheels are generally used for very hard materials, and hard bonded wheels for medium and soft materials. It is best to use a medium-grade wheel for grinding brass or bronze. One of the factors that must be taken into consideration when a wheel is selected, is the arc of contact between the work and the grinding wheel. Harder bonded wheels must be used for grinding small diameters than for grinding large ones, and soft wheels are the best for surface grinding.

The harder grades of corundum and alundum wheels may be run at speeds from 5000 to 7000 feet surface-speed per minute; the softer grades should not be run at a rate exceeding 5000 feet. Carborundum and crystolon wheels should be run a little more slowly. For cylindrical grinding, wheels should usually be run from 5000 to 7000 feet per minute;

for surface grinding, about 5000 feet per minute, and for cutter grinding, from 4000 to 5000 feet per minute.

Since the proper selection of grinding wheels is closely related to their efficiency, it is desirable that the choice of grade and grain and of the various speeds and feeds should be referred to the makers of the wheels, wherever there is much grinding to be done. As grinding is a specialized field, these firms have experts whose entire time is given to advising customers as to just what will best suit their needs, and naturally such help is of the very greatest value.

Mounting of Wheels.—In view of the high speeds, just mentioned, it is obvious that the wheels should be absolutely steady in order that there be no excessive vibration, with its accompanying danger. As there is always the possibility that bonded wheels may become ruptured, however well mounted they may be, the operator should be protected, whenever possible, by a hood like that shown at a. Figure 141. This is made in such a way that if the wheel should break. the operator would be practically secure against injury. Wheels should be mounted, as shown in Figure 140. between two safety flanges, which preferably should not be less than one-half or one-third the diameter of the wheel. These flanges should bear on the wheel only at their outer edge, and a compressible washer of rubber or blotting paper should be interposed between them and the wheel.

A wheel so mounted is held near the rim; consequently the centrifugal strains are much less than

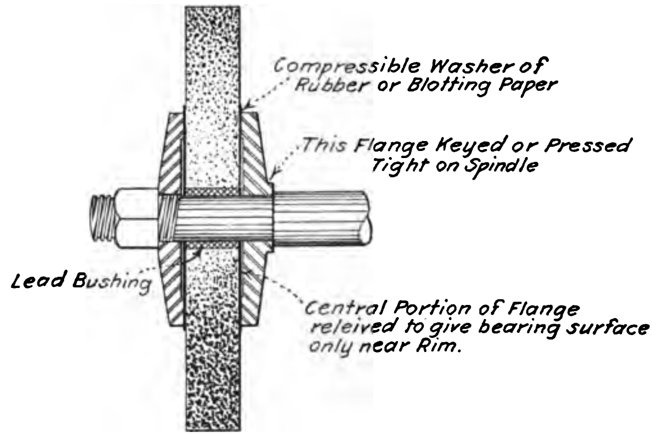
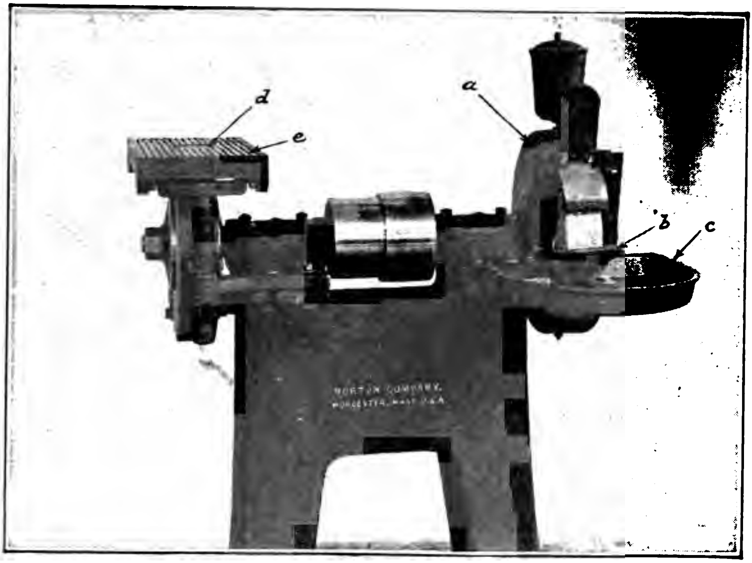


FIG. 140. CORRECT MOUNTING FOR A GRINDING WHEEL

they would otherwise be. When the wheel wears down toward the edge of the flanges, a smaller pair may be used. Many grinding wheels have straight sides, but those with sloping sides are naturally somewhat stronger against bursting, since the flanges have a better hold. Even when there are safety flanges, protection hoods should be used. The laws of most states require the removal of the dust—which is a menace to the health of the workman—by means of some exhaust system. In such instances a hood is required anyway, and it can easily be made strong enough to furnish complete protection. The working speeds, as given by the good makers, allow a factor of safety of from 6 to 12, and all wheels over five inches in diameter are tested at a speed nearly twice that for which they are recommended.



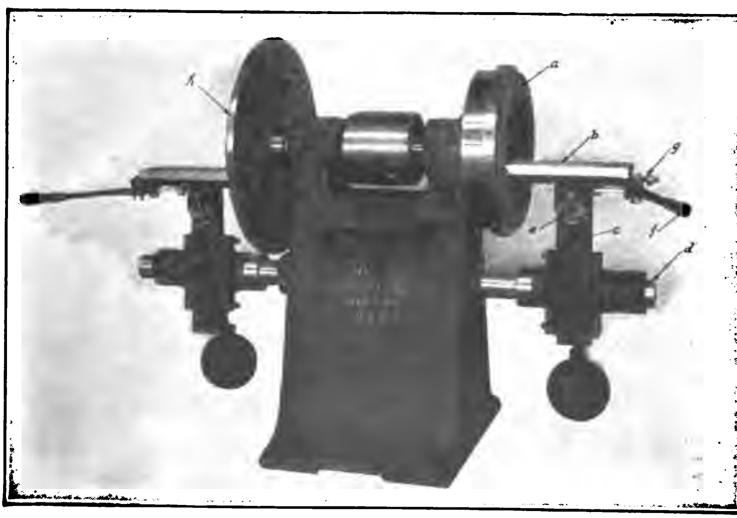


FIG. 141. NORTON GRINDING WHEEL STAND

FIG. 142. GARDNER HORIZONTAL DISC AND RING GRINDER

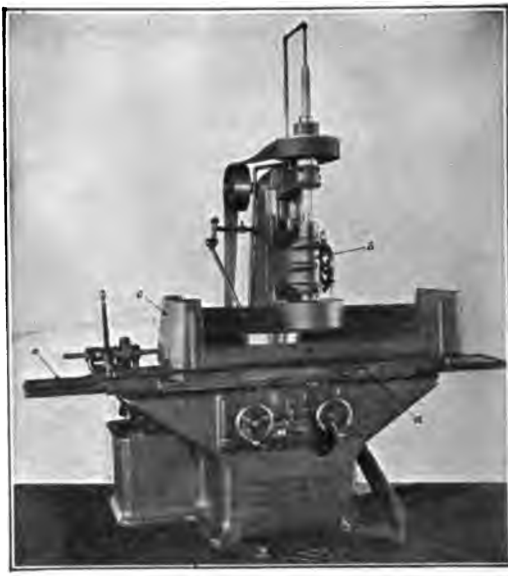
Types of Grinding Machines.—The simplest type of grinding machine is a plain emery-wheel stand, one of which is shown in Figure 141. These may mount one or two wheels. The commonest way of using a wheel is shown on the right. The wheel is used on the outer surface, and the work, which is pressed up against it by hand, is supported by the adjustable rest, b, which is set up as close to the wheel as possible without bringing it into contact. When wet grinding is done, the pan, c, is made to catch the water. Another way to arrange a wheel is to have the top of it project slightly up through an opening, d, in a surface plate, e. Then if the work is passed backward and forward over the wheel, an approximately flat surface can be obtained.

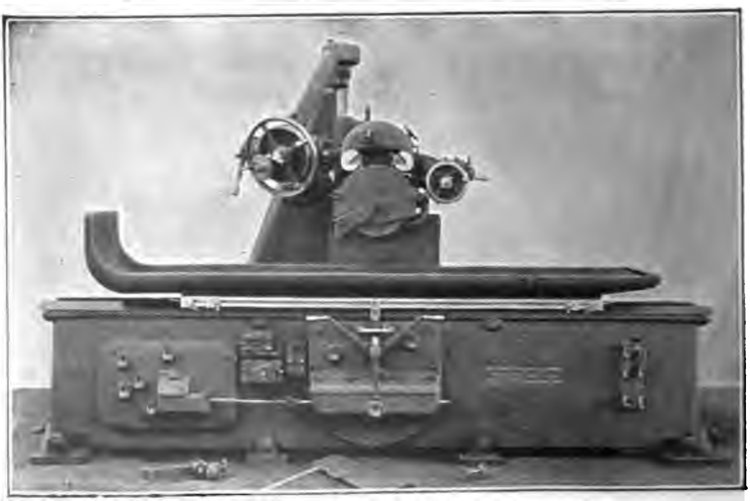
Another and much more accurate way of obtaining a flat surface is to use the side of the wheel, as shown in Figure 142. In this case, also, there is a double-ended stand with a horizontal, ball-bearing spindle that has on the right a vitrified ring wheel, which grinds on the face, a. The work is supported on the table, b, either directly or by a suitable fixture. The table and the carriage, c, may be swung backward and forward across the face of the wheel on the rocker shaft, d. The table may be set square, as shown, or tilted on an angle and locked in that position by the bolt, e; it may also be raised and lowered. The work is pressed up against the wheel by the handle, f, and the amount of forward motion may be controlled by the micrometer stop, g. On the other end of the machine is a disc wheel, h. This wheel, which is of steel, has an abrasive cloth or

paper mounted on its face. Very large wheels of this type are made which run in a horizontal plane. The pieces to be ground are placed on top of the wheel, but they are kept from rotating with it. Their own weight furnishes the necessary pressure. There is no danger that the disc wheel will burst. This wheel is being widely used for many kinds of surface grinding.

For still more accurate surface grinding, machines of the types shown in Figures 143 and 144 are used. The vertical grinder, Figure 143, uses the face, a, of a cup-shaped wheel. This type of machine is both accurate and very efficient for work on large flat surfaces; it is made in sizes large enough to grind faces 25 inches wide and 6 feet long, or circular ones 30 inches in diameter. Such a machine will finish many kinds of work formerly done on the planer or milling machine with greater accuracy and at less cost. The ring wheel is clamped to a circular flange at the lower end of a vertical spindle. It is reinforced against bursting by an adjustable steel band, which may be set up as the wheel wears.

The wheel spindle is carried in an adjustable counterbalanced head, b, which has a sensitive vertical feed operated either by hand or automatically. Provision is made for automatically disengaging the feed when the proper depth of cut has been reached. A pump supplies an abundance of water, which is delivered through the spindle; the centrifugal force drives the water out between the wheel and the work, keeping both cool and free from dust. A stream is also provided outside the wheel for cleansing pur-





FIGS. 143 AND 144. SURFACE GRINDERS
The vertical grinder in the upper view is built by Pratt & Whitney Co. The horizontal grinder below is built by the Norton Grinding Co.

poses. The table is provided with a high water guard, c, which catches the water and returns it to the supply tank.

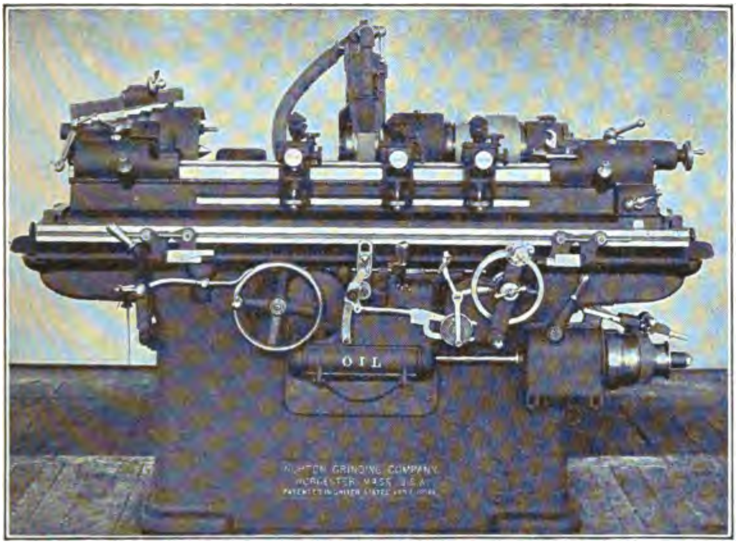
Various forms of chucks are used to hold the work. These may be circular with an automatic rotary feed, in which case the table is partly under the wheel, as shown in the illustration. This arrangement permits of setting the work on the exposed portion of the table while the grinding operation is going on; thus the action of the machine is continuous. For plain flat pieces, especially when they are thin, as in the case of saw blades, magnetic chucks are used to great advantage. When rotary chucks are used, the table remains stationary, and the only feed is rotary; for long work, the table may be given a transverse feed motion along the bed. The length of travel is governed by means of suitable dogs, d, at the front of the table, which act like those described in connection with the planer, Figure 86. In this machine, as in other types of grinding machines, the table is provided with extensions, e; these protect the ways from water carrying abrasive dust, which would tend to wear them away.

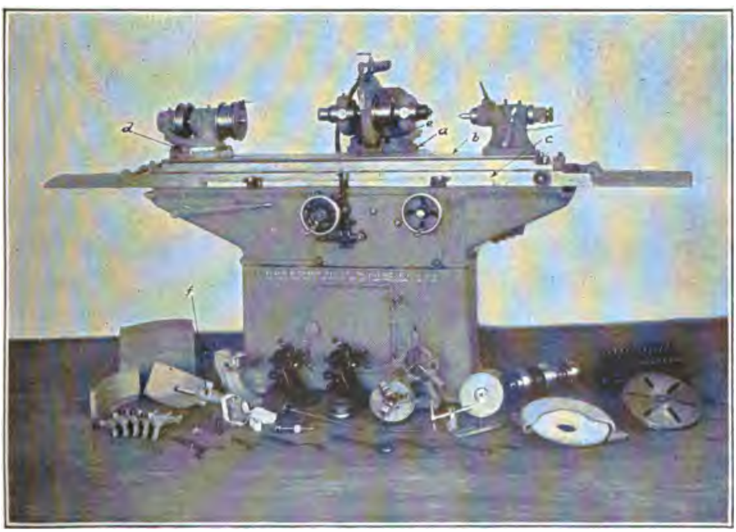
In the open-side surface grinder, shown in Figure 144, the grinding is done on the edge of the wheel instead of on the face. This machine can therefore be used for finishing grooves, irregular shapes, and surfaces that have projections. The work is carried on a slotted surface on the table, which is between the sides of the water guard and does not show in the photograph. This surface is 15 inches wide, and from 6 to 14 feet long according to the length of

the machine. The wheel head mounted on the upright carries a wheel 14 inches in diameter, which can be raised to give a clear distance of 17 inches to the surface of the table; when it is raised, a magnetic chuck can be used on a supplementary table. The work has a horizontal traverse under the wheel, and there are accurate adjustments for controlling the depth of cut. The travel of the table is controlled by adjustable dogs, as in the machine just described.

Figure 145 shows a plain cylindrical grinding machine used for producing cylindrical and conical surfaces. This type is used for finishing surfaces that have been roughed off in a lathe to within 1/64 or 1/32 of an inch of the required size. In addition to the rapid rotation of the grinding wheel, these machines have the following motions: a slower rotation of the work, as in a lathe, of from 25 to 75 feet per minute; a traverse of either the wheel or the work longitudinally of from one-fourth to three-fourths the width of the emery-wheel face for each revolution of the work; a cross feed or adjustment for setting the wheel to give the proper diameter of work. Most machines have also a horizontal swiveling adjustment that can be used in the grinding of tapers.

The feeds that govern the depth of cut have a range from .00025 inch to .004 inch with each reversal of the table, and are automatically thrown out when the work is down to size. The wheel spindle is of chrome-nickel steel, hardened, ground and lapped, and is capable of carrying a wheel 20 inches in diameter and 3 inches thick. The speeds of the wheel, the work, and the feed of the table are en-





FIGS. 145 AND 146. GRINDING MACHINES

The plain cylindrical grinder above is built by the Norton Grinding Co. The universal grinder below is built by Brown & Sharpe Mfg. Co.

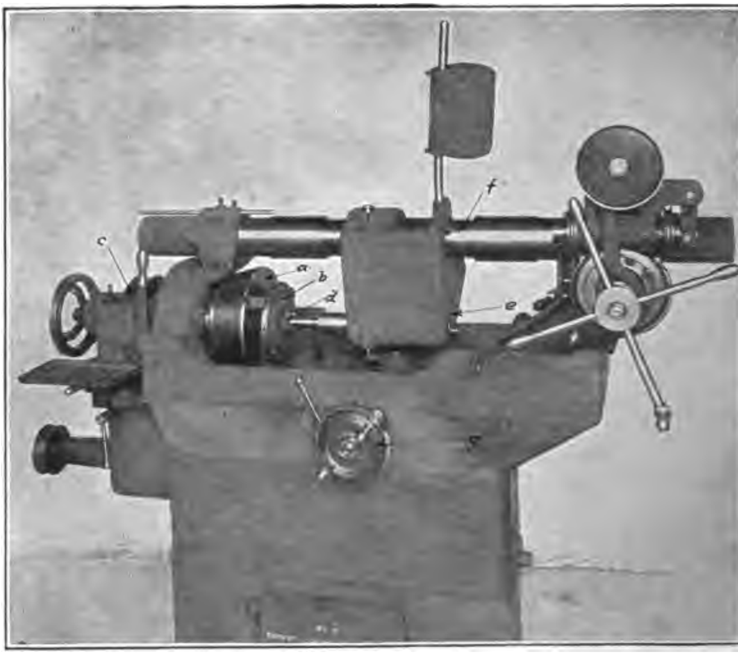
tirely independent of one another; the wheel speed varies from 1360 to 1630 r.p.m., the work speed from 27 to 207 r.p.m., and the feed of the table from 21 inches to 126 inches a minute. Three steady-rests are provided for supporting slender work, and provision is made for an abundant supply of water—the tank and pump are located inside the bed of the machine. In this machine, as in all other high-grade grinding machines, all the working surfaces are protected from grit-bearing water, which would soon destroy their accuracy. All changes are effected from the front of the machine.

Figure 146 shows a universal grinding machine that has a wider range of work. The wheel stand in this type of machine has a horizontal swiveling adjustment, a, so that the wheel can be set in any position without interference. The upper portion, b, of the table has a swiveling motion about a central stud in the lower part, c, and the headstock also swivels, at d. By means of these adjustments, any taper to be ground may be handled accurately. In addition to the swiveling adjustment, the wheel stand has a hand-operated transverse adjustment that can be set to thousandths of an inch, and an automatic cross feed of from .00025 to .004 inch, which operates at each reversal of the table and throws out when the work is to size. In Figure 146 the steady-rests and the other equipment necessary are shown on the floor. An internal grinding fixture, f, consists of a separate head with an independently driven spindle, on the end of which a small wheel may be mounted for grinding out small holes and cylinders.

Figures 147 and 148 show two machines designed especially for internal grinding. The Bryant grinder, shown in Figure 147, has a chuck, a, in which is mounted the piece to be ground, b. This chuck, with the work, is given an independent rotation by the pulley, c, in the fixed head of the machine, and the grinding wheel, d, is carried on the end of a shaft mounted in the head, or box, e, which depends from the heavy bar, f. A belt, not shown, drives the grinding spindle from a pulley, which is inside the box, e. For the longitudinal motion of the grinding wheel a traverse is given to the bar, f, by the mechanism at the right, operated either automatically or by hand. An arm projects downward from the swinging box, e, and by bearing against a former, or control-plate, inside the frame, controls the forward and backward position of the wheel, as well as the diameter being ground.

The control-plate against which the arm bears may be straight and set parallel with the axis for cylinder grinding, or on a taper for taper grinding, and its position may be adjusted by a feed screw under control of the mechanism, g, at the front of the machine. The control-plate need not necessarily be straight and by giving it a curved contour irregular shaped holes may be ground. By turning the feed screw the control-plate inside may be moved in and out for varying the depth of cut. A stop-pin, h, prevents the wheel from swinging forward far enough to strike the opposite side of the hole.

In the machine shown in Figure 148, the work is mounted on a table that carries the work across the



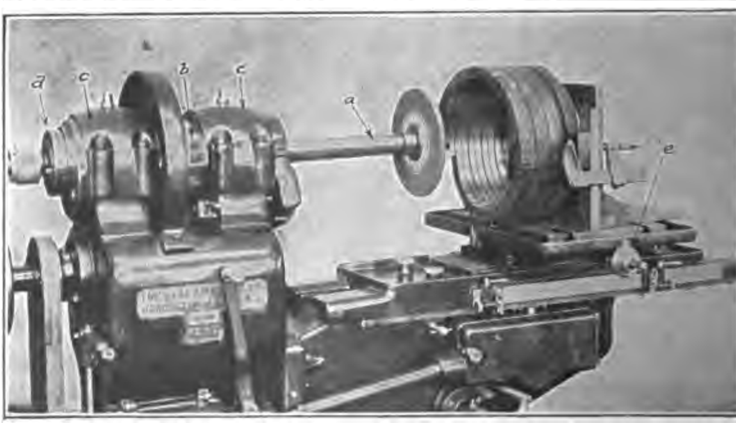


FIG. 147. BRYANT CHUCKING GRINDER

FIG. 148. HEALD INTERNAL GRINDING MACHINE

wheel with an automatic transverse movement to and fro. The wheel is mounted on the end of a spindle, a, which is driven from the small pulley at the extreme left. This spindle is adjustable eccentrically in a larger one, b, which rotates about a fixed axis in the main bearings, c, of the head. The outer spindle, b, has a slow rotation that carries the axis of the spindle, a, around in a circle, the diameter of which is determined by the amount of eccentricity between the two axes. The grinding wheel therefore has two motions: a rapid rotation about the axis of its own spindle, a, which gives the cutting speed; and a slower one about the axis of the spindle, b, which gives a circumferential motion of the wheel as a whole around the inside surface of the work. The degree of eccentricity can be varied, by means of an adjustment at d, to suit the amount of travel that it is necessary to give the wheel. The depth of cut is controlled by the micrometer screw, e.

This form of internal grinder is useful for finishing the bores of automobile cylinders and other parts that cannot be conveniently mounted for rotation. When the work can be easily turned, it can be mounted in a chuck on the head of the machine, and the wheel can be mounted at the end of a spindle carried by the sliding table. The work spindle and the wheel spindles are given independent rotations by means of separate belts, and the depth of cut is controlled by an adjusting screw on the side of the table, as shown in Figure 148.

Tool Grinders.—Grind stones are used only for thin-edged tools, such as cutlery and wood-working

tools. In modern shop practice, cutting tools are no longer ground by hand on an emery wheel as formerly. Correct shape and proper cutting angles are essential factors in good tool performance, and these can be had only if grinding machines are used. Furthermore, in milling cutters and reamers it is essential that all the teeth be ground uniformly, and this cannot be done by hand.

For this work a large number of tool grinders have been developed, which fall into three general classes: First, cutter and reamer grinders, for sharpening the multiple edges of milling cutters and reamers. In this type the tool is mounted on centers or an an arbor, and each face is brought for grinding, up to a definite position, which is determined by a stop. In this way uniformity is obtained for the various teeth. Second, twist-drill grinders. In these, the drill is carried on a holder, which is set at an angle of about 60 degrees to the face of the wheel, and which is then given a rocking and sliding motion as it is moved past the wheel. Thus a slightly relieved conical surface is produced. The drill is then turned over and the other flute is ground, provision being made that the two surfaces shall be alike. Third, universal tool grinders, which are used to sharpen all kinds of lathe, planer, and shaper tools. The tool is clamped into a holder, which can be rotated about horizontal and vertical axes, which is also capable of sliding. The relationship between the various movements is complex, but they are under the control of adjustments that can be so set that exact shapes and angles can be ground by comparatively unskilled

labor. With them it is possible to grind any face at any angle, and to duplicate the pattern indefinitely.

Polishing and Buffing.—Polishing and buffing are finishing operations somewhat allied to grinding. No attempt is made, however, by means of them to alter or control the form of the piece; they are used merely in polishing the surface or in preparing it for plating or for some other surface finish, such as blueing or lacquering. Polishing wheels often are made of wood and have around their circumference leather strips that are impregnated with emery or other abrasive material. Another type of wheel is made of steel, and is about 12 inches in diameter and 2½ inches across the face; over the face is a strip of cloth carrying the abrasive, which may be changed from one grade to another or renewed when worn. Wooden and steel wheels are used on work where it is necessary to maintain good edges. The steel wheels, which are safer and generally more economical, are used largely in cutlery manufacture.

Buffing wheels are made of disks of leather—or sometimes of cloth, such as canvas, muslin, or felt. They are clamped between two steel plates, and their outer edges are impregnated with grinding material, rouge, and the like. Wheels of this kind are used in plain stands, similar to those shown in Figure 141, and the work is manipulated by hand. Canvas and muslin wheels are used for polishing irregular pieces, as the wheels are soft and when the work is pressed against them they will conform to a curved surface. Belts faced with grinding dust, which run from 2000 to 2500 feet per minute, are also used with good results.

CHAPTER XXII

BROACHING AND PRESS WORK

The Broaching Process.—In its usual application the broaching process consists in forcing an elongated cutting tool, which has a varying cross-section, and multiple cutting edges along the sides, through a hole already formed, thereby changing the shape of the hole. Formerly the broaching tool was pushed through by a press, and for some purposes—provided the tool can be very short—this is still done. Nearly all broaching, however, is now done by pulling the broach through the hole. The initial hole is ordinarily drilled at right angles to some face already machined, as in the majority of the samples shown in Figure 150, but it may be forged or rough-cored and of rectangular or other shape, as in the case of the steel revolver-frame and the cast iron stand, shown at the left. Typical broaching tools for pulling cuts are shown at each side of the illustration.

The broaching process is applicable in finishing square, hexagonal, or odd-shaped holes, in cutting single or multiple key-ways in hubs, and in forming the teeth of small internal gears, ratchets, and the like. It was formerly used almost entirely for interior work, but recently has been extended to exterior work; it may be used in broaching the teeth on

small spur gears when the quantities required are large enough. The chief disadvantages of the process are the high cost of the broaching tools and the uncertainty of their life, but these are much more than offset by its speed and accuracy, and its adaptability in connection with a wide variety of irregular forms, as well as by the fact that the work can be done by comparatively unskilled labor.

It is said that broaching was first used by Mr. R. S. Lawrence, at the Sharps' Rifle Works, in Hartford, about 1853, and for many years it was employed only in the manufacture of guns and similar articles. All of the early broaching tools were pushed through the work by a press; consequently, since the tools were under compression, they had to be short and of fairly large cross-section, or they would buckle and break. In good practice not more than from .001 to .003 inch of the metal should be removed per cutting edge, and sufficient space should be left between the tools for the chips to accumulate during the cut, which means that they cannot be much less than five-eighths of an inch apart. Therefore, when there is a marked change in the shape of the hole, a long succession of cutting edges is required.

Since push-broaches cannot be made over a foot long, however, in the early days of broaching the work had to be divided among a number of broaches which were used in succession; the first one started with the original round hole, and each succeeding one continued the operation from where the previous one had left it. Sometimes as many as ten or a dozen broaches were required. The handling of so many

tools involved considerable labor, and more or less danger of breaking them if they were used in a wrong order. Even under these handicaps the broaching process produced certain kinds of work much more cheaply and satisfactorily than any other method. In modern manufacture the broach is pulled through the work; consequently it is under tension only, and may be any length convenient to handle. Thus the danger of breakage is lessened, and the number of tools to be handled is reduced. This modern type of broach has practically superseded the other and less convenient one.

The Broaching Machine.—The modern form of broaching machine is shown in Figure 149. It consists of a square, box-like upright or standard, a, which contains the operating mechanism, and a long horizontal extension, b, of U-shaped cross-section. Between the upper ends of the U are guides carrying a draw-head, c, which slides backward and forward along the top of the extension. Secured to this head is a long screw, d, which can just be seen between the guides. The screw is fixed in the draw-head and does not rotate. The power to operate the machine is carried from the pulleys at the extreme right through a shaft to a pinion in the casing which drives the large gear, e, to which is secured a threaded sleeve, engaging the screw, d.

The revolution of this gear and its sleeve moves the screw and the draw-head to the right to make a cutting stroke. At the end of the extension, b, is an annular finished face, f, which is perpendicular to the motion of the draw-head. This face carries a

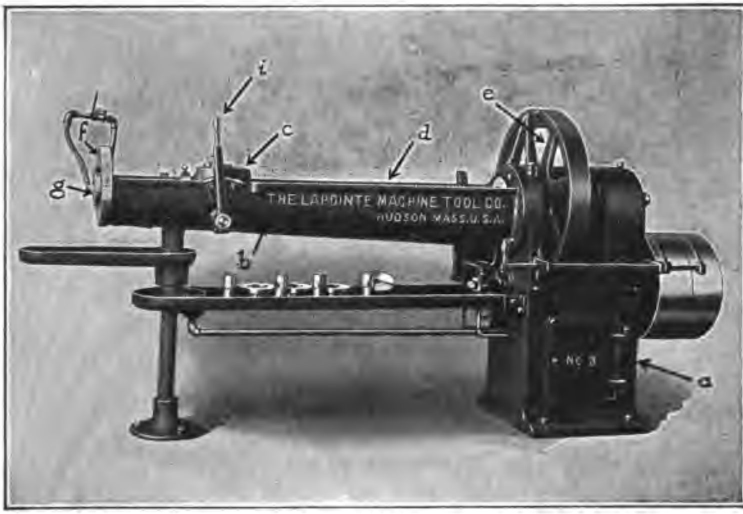


FIG. 149. BROACHING MACHINE

suitable work-holder, g, one kind is shown in place, and others are shown in the pan below. The work to be cut is set into the work-holder, g, and a broaching tool similar to the one shown at a, Figure 150, is inserted through the initial hole in the piece and keyed to the draw-head by means of a loose key slipped through the slot, b, Figure 150.

Broaching Tools.—Figure 150 shows four broaches; in the one at a, the shape gradually changes from round at the upper end to square at the lower end. This type would be used for such a hole as that shown at c. The broach, d, would be used for cutting a series of notches or splines, as shown at e. For a single key-way, as at f, a broach of the type shown at g would be used. This is rectangular in cross-

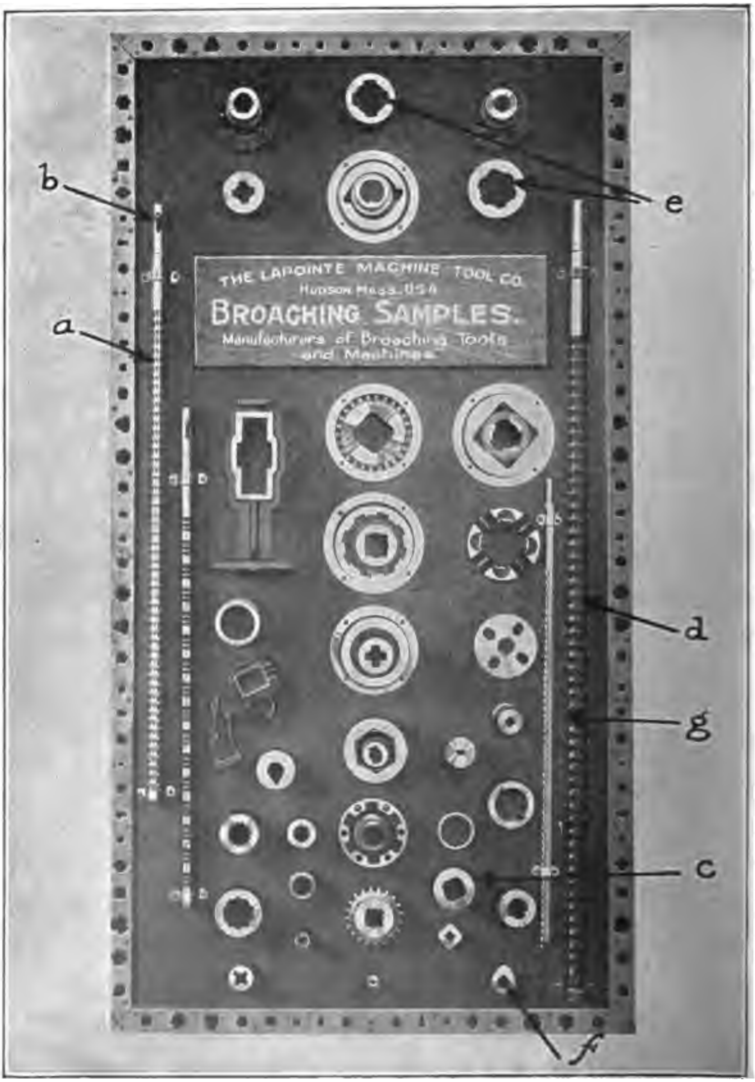


FIG. 150. BROACHES AND SAMPLES OF BROACHING WORK

section, with the cutting teeth along one edge only. The piece to be cut is mounted on a projecting stud, a, Figure 151, on the work holder, which is slotted at b to receive the broach and guide it so that only the cutting edges can project. The small end of the broaching tool is inserted through the work and the slot, b, in the supporting stud, and secured to the draw-head. The handle, i, Figure 149, is then thrown over, and the head, carrying the broach with it, moves to the right. The teeth are set on an incline; as the motion starts, the teeth begin to appear above the surface of the stud, a, and cut deeper and deeper until the full depth is reached. The last few teeth, c, are the final shape required, and serve to bring the work accurately to size.

This feature in broaching tools accounts in large measure for the accuracy of the process. The previous cutting edges leave little work for the sizing edges to do and if the first of these wears, the second can take up its work, and so on, until the last one has been worn out. When the broach has been pulled all the way through the work and holder, it lies in the extension, b, Figure 149. It is removed from the draw-head; then the handle, i, is reversed, and the draw-head is brought back to the starting position by a rapid return traverse. A new piece is set in place, the broach is inserted through the hole in the work and secured once more to the head, and the machine is again ready to start. The broaching process is not confined to straight cuts; helical cuts also may be made, provided the pitch of the helix is not too steep.

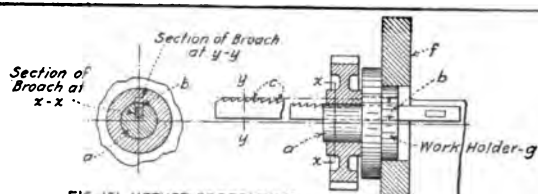


FIG. 151 METHOD OF BROACHING KEY-WAYS

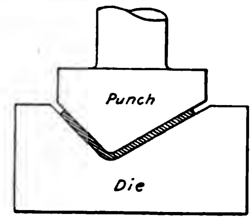
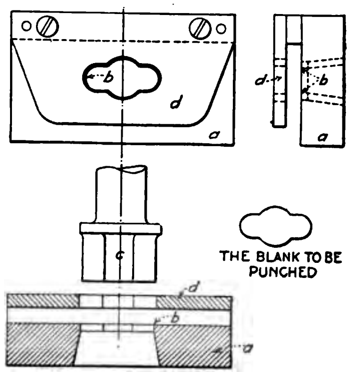


FIG. 153 BENDING DIE



THE BLANK TO BE PUNCHED

FIG. 152 BLANKING DIE

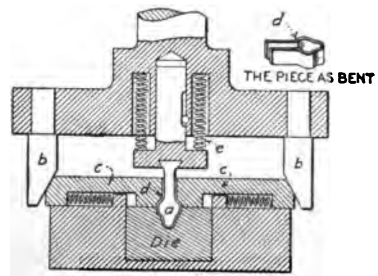


FIG. 154 COMPOUND BENDING DIE

FIGS. 151-154. BROACH AND DIES

Broaching machines of the draw-head type are capable of making strokes up to 50 inches, so that long broaches can be used with the resulting saving in both tool expense and operation. This process is being applied to larger and heavier work, since its economy of operation and accuracy of output make it a valuable method wherever there are quantities sufficient to justify the expense of the tools.

Punches and Dies.—Press operations, which are done with punches and dies, may be either cutting or forming, or a combination of both. The cutting is always a shearing action, as in cutting up bar or sheet stock, punching holes of almost any shape, or trimming off the raw edges of pieces after they have been formed. The shaping or forming operations are in reality cold forging, and comprise bending, forming, bulging, embossing or coining, cupping and drawing, or heading and upsetting. Nearly every operation calls for a different die, and we can describe here only a very few of the better known types. These are used generally on sheet-metal stock of steel, wrought iron, brass, copper and, in the case of jewelry, of the precious metals. The tools consist of two main parts, a die of one or more pieces, which is secured to a fixed bed in the machine, and a punch carried in a reciprocating head, the motion of which is controlled by some form of clutch.

One of the simplest forms is the plain blanking die, Figure 152, which consists of a die, a, with cutting edges, b, formed to give the proper shape, and the corresponding punch, c. The strip from which the blank is to be cut is laid over the opening; the

punch descends through the die, carrying the blank with it. Generally there must be a stripping piece, d, which reaches over the top of the sheet metal and holds it in place as the punch rises. This piece strips the metal off the punch and leaves the sheet free to be fed along for the next piece. Several punches may be combined in one fixture and all do the same kind of work, or they may perform a succession of operations one after the other. When they perform the same kind of work, they are known as gang dies; when they work in series, each punch making its own cut, they are known as follow dies. The simplest form of bending die is shown in Figure 153. The face of the die is shaped to conform to the contour desired, and the punch forces the work down into it. The action is so simple that it needs no explanation.

Two or more bending operations may be performed in a compound bending die, as shown in Figure 154. In the one shown, the work is carried down into the die by the punch, a, and held there while the beveled fingers, b, acting upon slides, c, in the die, force them inward and produce the bend, d. On the upstroke of the head the slides, c, are thrown out by springs; the finished piece rises with the punch, and may be slipped off when it is clear of the die. When the punch performs several operations, as in this case, it is usually necessary to introduce a spring connection, e, which will allow the main portion of the punch to descend and effect the second motion while the punch stays at rest. Remarkable ingenuity is displayed in the design of dies of this character, which are sometimes quite intricate.

Figure 155 shows a double-action die combining cutting with drawing, which is but a form of bending. In this instance there are two sliding heads, one of which carries the punch, a, which cuts out a round disc by shearing against the cutting edges, b, of the die, c. The punch, d, then descends and pushes the blank through the hole, e, forming the shell as shown.

Plain drawing dies repeat the action of the parts c and d as the shell is progressively forced through holes—each smaller than the one immediately preceding—and drawn out from the shallow cup into a longer one and even into a tube. Such redrawing dies are characteristic tools in the manufacture of cartridge shells. All materials drawn in dies in this way must be annealed from time to time as the work progresses, because after a certain percentage of "drawing down" they become brittle and their ductility must be restored. This is done by heating them to a red heat and allowing them to cool.

Figure 156 shows a combination die used for cutting a blank and, at the same stroke, turning down the edge and drawing the piece into the required shape. The work is blanked by the cutting punch a, and formed to the right shape by b and c. The former holds the piece by spring pressure against the block, c, while the punch, a, continues to descend, and draws the work into the required shape. The ring, d, acts as an ejector, throwing out the piece as the punch rises on the return stroke. The flange or edge, e, which is left turned out, is sure to be irregular in shape. When it is necessary to have

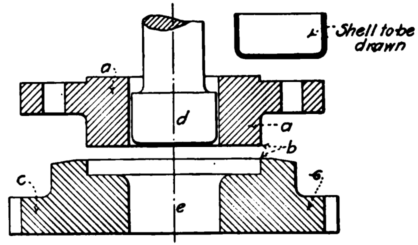


FIG. 155 DOUBLE ACTION CUTTING AND BENDING DIE

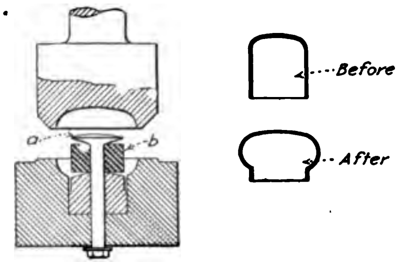


FIG. 157 BULGING DIE

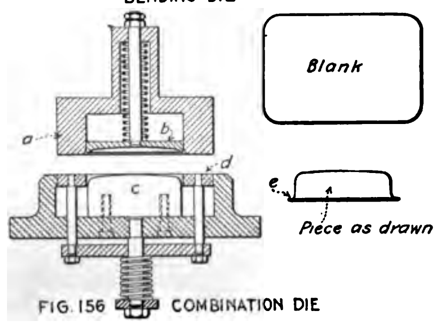


FIG. 156 COMBINATION DIE

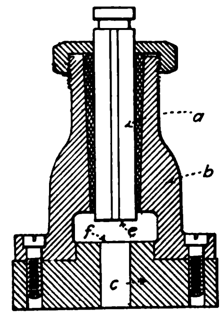


FIG. 158 SUB-PRESS DIE

FIGS. 155-158. DIES AND THEIR ACTION

this smooth, the edge is cleaned off in a trimming die somewhat similar to that shown in Figure 152.

Figure 157 shows a bulging die which enlarges a cup, similar to that formed in Figure 155, to the rounded shape shown. The drawn shell is placed over the mushroom plunger, a, in the die, and when the punch descends the rubber disc, b, is forced out, expanding the shell into the curved chamber formed by the punch and the die. As the punch rises, the rubber returns to its original form and the expanded work is then removed.

The most accurate type of die is the sub-press die, shown in Figure 158. In all the dies above described, the machine is depended upon for the accurate registering of the punch with the die. The sub-press die is self-contained; the punch, a, slides in an upright, b, which is secured to the base, c. The only function of the machine is to depress the top of the punch, a; correct alignment is obtained from the proper registering of the pieces a, b, and c. Dies of this character are used in the manufacture of watches, for punching out wheels and other parts, and they can be made to do work requiring extreme accuracy. The finer parts (not shown) are secured to the faces e and f of the punch and die.

Types of Presses.—The simplest form of press is the foot press, shown in Figure 159. These machines are used in jewelers' work, and for light operations on small pieces. They may be mounted on independent stands, as shown, or in rows along a bench, and are usually operated by girls or boys. The die is set on the base, and the punch is carried in the slid-

ing head, a, mounted in the frame of the machine. The motion is derived from a toggle joint actuated by a heavy pendulum, b, which is pushed back by the foot treadle, c. By means of the adjusting screw, d, the head may be raised or lowered to accommodate different heights of work. In another type of hand press which is widely used, the head is forced down by means of a sharp-pitched screw, which occupies the place of the adjusting screw, d. Across the top of this screw is a horizontal arm, which carries at each end a heavy cast-iron ball. A handle drops down from the arm to a point within reach of the operator, who, by pulling this handle, revolves the screw and the heavy weights and forces the head down against the work.

For larger work the belt-driven press, Figure 160, is used. This consists of a heavy C-shaped frame which leaves the sides clear so that strip stock can be fed across the die from side to side. When the back is open, as at a, the press is known as an open-back press. The opening permits light from the back of the machine to fall on the die, and also provides an egress through which the stamped articles may be discharged. In this type of press the main frame, b, is usually separate from the legs, c, and is clamped to them by means of a fitted connection, d, which is on the arc of a circle.

By the turning of the worm, e, in the base, the frame, b, may be tilted backward at an angle, an advantage often convenient in connection with certain types of work, since the finished piece will then slide away from the opartor and out through the

FIG. 159. FOOT PRESS

FIG. 160. BELT-DRIVEN OPEN BACK PRESS

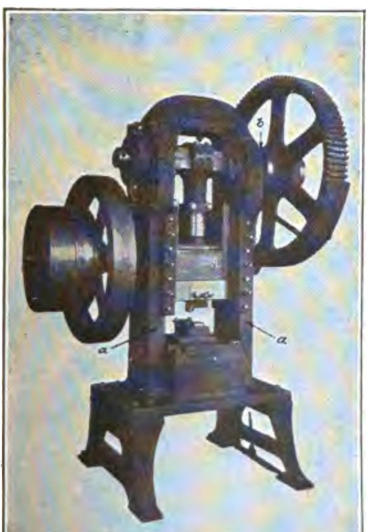


FIG. 161. BACK-GEARED PILLAR PRESS

FIG. 162. KNUCKLE-JOINT PRESS

opening in the back into a drum or receptacle behind the machine. The punch head, f, is operated through a connecting rod from the crank, g, between the housings on the top of the frame. This crank is part of shaft, which extends to the right and carries the driving pulley. The pulley is generally made with a heavy rim, so that it acts as a flywheel as well. It is not keyed to the shaft but rotates freely, except when a clutch on the side of the machine between the pulley hub and the frame is thrown in.

This clutch does not show in the figure. It is operated by the foot treadle, h, shown below. Much thought has been given to the subject of press clutches, as the work they are called upon to do is very severe. They are usually arranged to lock the pulley to the shaft when the treadle is depressed and held there. If the treadle is depressed and the foot is removed at once, the crank shaft will make one revolution and stop automatically at the top of the return stroke, in the position shown. The work is then fed forward and the treadle is depressed again. For continuous operation it is necessary only to keep the treadle depressed. The connecting rod is made in two sections, which may be clamped together by the screw, i. Thus an adjustment for length is given which allows setting the head to different heights for varying jobs.

Figure 161 shows a straight-sided or pillar press, which is much stronger than the one just shown, but in general not so convenient. Here the connection between the base which carries the die and the bearings above, is made by two straight members a, a,

which are free from the bending strain incident to the open-back type. This press is back-geared, the belt runs on tight and loose pulleys at the left, and the flywheel is separate from the pulleys. The pulleys and the flywheel are carried on a separate shaft at the back of the machine, and this shaft has a pinion at the opposite end engaging with the large spur wheel at the right. The clutch is located, as in the machine just described, at b, between the frame and the hub of the large gear.

Figures 160 and 161 both show single-action presses; that is, there is one head with its connecting rod and crank. In a double-action die, such as that shown in Figure 155, it is necessary that there be two heads. One of these is usually arranged to slide inside the other, and the shaft above has three crank pins—one in the middle, which operates one head; and one on each side, which act together and operate the other head. Such presses are known as double-action presses. Triple-action presses are also made, in which the third motion is usually given to an independent head that acts upward through the lower die.

A still more powerful type of press is the knuckle-joint press, Figure 162, which usually has the pillar type of frame. The shaft, however, instead of driving directly down to the head, operates a toggle or knuckle joint. The upper member, a, connects with the arch of the frame, and the lower member, b, with the head, c. A short link extends forward from the crank on the main shaft, d, to the joint between the toggle members, a and b. Presses of this type have a

very short stroke, but tremendous power; they are used for embossing, coining, and so on. Hydraulic presses, also, are used for heavy work, especially where the stroke is long. These, however, are not used so much for cold pressing as for hot forging. A heavy forging press is shown in Figure 20.

The types of presses are often subdivided according to the use to which they are put and the methods of feeding the work. A coining press is a knuckle-joint press especially adapted, as the name implies, for coining work. Trimming presses are used to cut off the ragged edges of pieces that have been blanked and formed. Other types are called multiple-punching, notching, or perforating presses, according to their use. A cut-and-carry press has multiple plungers, each of which does a different operation. The stock is fed in from one side and moved across from station to station with each stroke of the head, and a finished piece comes out on the other side at every stroke. In a dial-feed press a circular work-holder, or dial, rotates about a central stud on the base; it has openings or stations around the rim. The dial is operated automatically by the punch, and the operator feeds the stations on the side toward him while work is being performed on the pieces that are on the other side. This is a safe and rapid form of feed, well adapted to long runs of standard work.

Safety.—Increasing attention is being given to the the question of the safety of the operator in feeding punching machinery. With no class of machines have accidents been more frequent. They usually come from the accidental throwing in of the clutch, from

the failure of the operator to get his hand away from the die quickly enough after he has thrown the clutch, or from an attempt to readjust the work on the die while the head is descending. Many safety devices have been developed. Some of them provide an automatic stop which locks the head so that it cannot descend until the operator's hands are clear of the die. Others hold the clutch until the operator throws a releasing mechanism which requires the use of both hands. And in another form, a guard is automatically interposed between the operator and the die by the clutch-throwing mechanism or by the head as it descends.

CHAPTER XXIII

WOODWORKING MACHINERY

Types of Machines Few; Modifications Many.—The natural peculiarities of wood constitute a factor that has strongly influenced the design of the machinery used for working it into useful shapes. Obviously wood cannot be cast or forged; hence woodworking machines are nearly all cutting machines. Wood is comparatively soft and brittle, and the chips clear themselves easily; therefore high speeds (5000 to 10,000 feet a minute) are the rule, with correspondingly fast feeds and high power consumption. Such speeds preclude reciprocating motion between the cutter and the work; the lathe, drill, milling and grinding machines are the only machine tools that have their counterparts in woodworking.

In spite of the small number of fundamental machines, each type has been modified in many ways to suit special conditions, so that today there is wide variety in the methods of holding and feeding the work, and in the arrangement of the cutting tools. Thus, the surfacer, the matcher, the moulder and the shaper* are developments of the planer; the hollow-

* Note.—These names must not be confused with those of metal-working machine tools, with which the tools here mentioned have no connection.

chisel mortiser is a form of borer; the circular saw, in effect a fast-running milling cutter, is used in plain and universal benches, swing frames, tenoning machines, log mills, and so on.

Saws.—Some form of saw is invariably used for cutting lumber roughly to shape. The circular saw has been used in the past to do most of this work, especially when straight cuts were required. The band saw has now superseded it in many cases. The great advantages of the band saw are its thinness, by virtue of which it wastes only one-third as much material as the circular saw, and its narrowness, which makes it suitable for use on curves and easy scroll work as well as for straight lines. A plain band saw for general purposes is shown in Figure 163. The cast-iron C-frame carries an upper and a lower wheel, a and b, each about 3 feet in diameter and faced with leather; the upper wheel bearing slides in vertical ways, and is pushed upward by a spring that keeps the correct tension in the saw, c, which passes over the wheels. The lower wheel shaft carries both tight and loose pulleys on the rear end, over which the driving belt passes; the belt shipper for starting and stopping the saw is operated by the handle, d.

The work is laid on the table, e, which can be tilted from zero to 45 degrees by a hand wheel (not shown), and which is fed by hand against the front edge of the saw. The thrust is borne by the roller guides, f, the upper one of which can be placed as close to the work as convenient by lowering the post, g. For safety's sake both wheels, and all except the working portion of the saw, should be inclosed, as shown

in the figure. The saws used vary from ½ to 2½ inches in width, have a brazed lap joint, run at a speed of 5000 feet a minute, and consume 3 to 5 horsepower.

For ripping and straight-edging, a heavier machine is used, with a saw 4 inches wide, and an adjustable guide or "fence" is attached to the left side of the table. The work is fed automatically, from 30 to 125 feet a minute, by two fluted rolls carried at the lower end of the post, g.

Band Saw.—The band saw is desirable for re-sawing timbers into boards, or a thick board into two thin ones, on account of its narrow slot, or kerf. For this purpose an in-feeding and an out-feeding pair of vertical feed rolls are used. All the rolls are power-driven and can be adjusted by a hand wheel for different thicknesses of work. For sawing warped surfaces, such as ship timbers, a special saw is used, both wheels of which are mounted on a circular housing carried on roller bearings by the main frame. The saw can be tipped 45 degrees to the right or left while working, so that it is possible to cut almost any skew shape with it.

Circular Saw.—In spite of the fact that the band saw can be used in a variety of ways, the circular saw is very often used in preference, especially when many long, straight cuts must be made. In its simplest form it is used in a plain saw bench, which consists of a four-legged, or box, frame supporting a smooth iron or wooden table, about 4 feet by 6 feet, and carrying a horizontal arbor on which is mounted a circular saw whose upper edge projects through

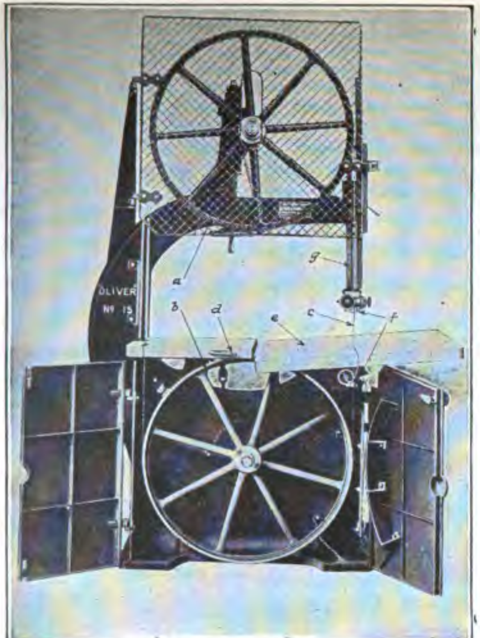


FIG. 163. BAND SAW

FIG. 164. UNIVERSAL SAW BENCH

Oliver Machinery Co.

a narrow slot in the table. A long fence for guiding the work is clamped to the top of the table; it can be shifted for ripping different widths, and can be tilted for sawing bevels.

The table can be elevated by a hand wheel or by a lever, so that the saw blade will protrude through the top of the work no further than is necessary to make a clean cut. The smaller sizes are hand-fed, but for heavy ripping and edging a two-roll feed is used, similar to that on band saws. A chain feed is sometimes used when a straight cut is absolutely essential. Such a feed consists of two endless chains which travel the length of the table, one on each side of the saw, in a recess made for the purpose, and return underneath through the frame. Each link has a serrated surface, against which the work is pressed by a row of weighted idlers acting from above.

Universal Saw Bench.—Gradual development of this type has evolved the universal saw bench, shown in Figure 164. The table consists of a stationary section, a, and a moving section, b, carried on rollers c. Both the stationary section and the moving section are carried on a rocker, so that the whole table can be tilted about a longitudinal horizontal axis through the saw slit, d. Two saws, a cross-cut, e, and a rip, f, are provided; they are mounted at each end of a yoke (not visible) carried in bearings in the main frame.

By the turning of a handwheel the yoke is swung in its bearings and either saw is brought into operating position. Two types of fence are provided: the ripping fence, g, which can be clamped at any angle

and at any distance from the saw; and the cut-off gauge, h, which may also be clamped at any angle, and which is provided with a guide strip that slides in the groove, i. All fences and gauges have scale and micrometer adjusting screws for making accurate settings. This machine is most useful in cabinet-making and pattern shops, where the degree of accuracy approaches that required in metal working.

Swing-Frame Saw.—The swing-frame saw is peculiarly fitted for cutting off to standard lengths, as in door, sash, and box factories. The work rests in a fixed position on a table, and the saw, whose arbor is supported in the lower end of a frame that hangs from the ceiling, is pulled through the work from back to front.

Log Mill.—A special apparatus, known as a log mill, is used for ripping logs and rough timbers into boards. It has two main parts: the husk, a, and the carriage, b (Figure 165). The former supports the saw, the arbor, and the feed mechanism; the latter holds the log and feeds it past the saw. The arbor is driven directly by the pulley, c; the forward feed is obtained by pulling the lever, d, to the right. This motion feeds the frame forward by means of a pinion meshing with the rack, e. For the return feed, or "gig," which is considerably faster than any of the forward feeds, the lever d is pushed to the left. The gauge-roll, f, with graduated adjustment, supports the left-hand side of the timber as it approaches the saw, and the spreader wheel enters the kerf and opens it enough to prevent the binding of the saw.

The carriage is a timber frame which travels on

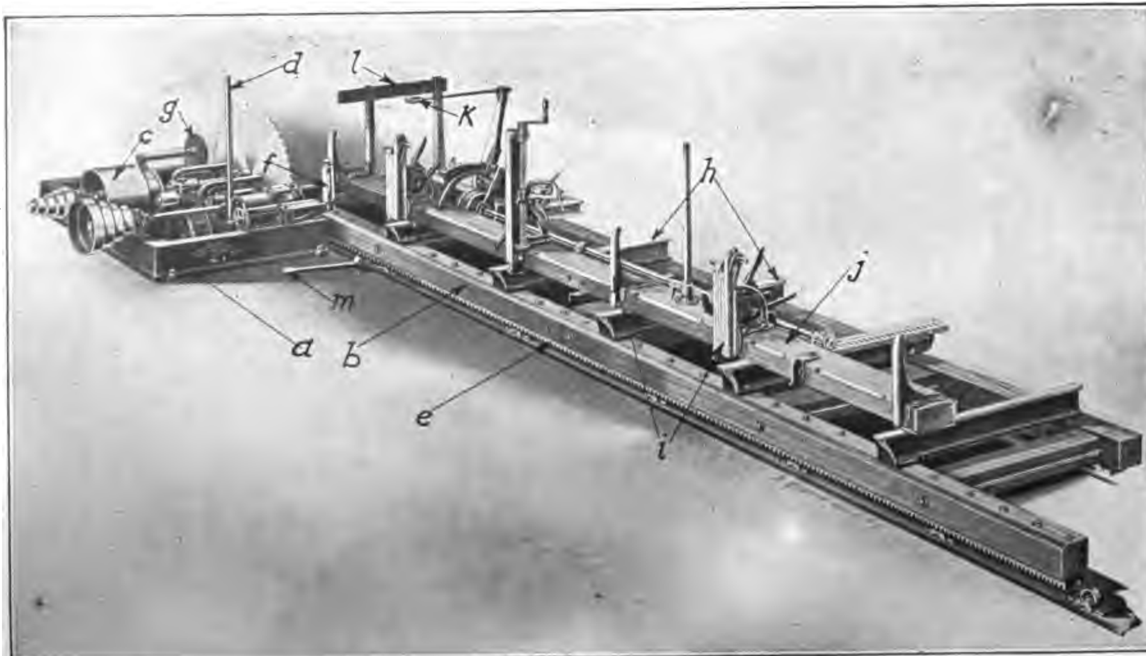


FIG. 165. LOG MILL
Lane Manufacturing Co.

rolls that are either stationary, as shown in the illustration, or fastened to the under side of the carriage stringers. Bolted to it are a number of head-blocks, h, spaced about five feet apart, which support the log on its under side; its right-hand side rests against the uprights, i, fastened to the set beam, j. The log is clamped rigidly to the uprights by hooks, or "dogs," of various styles, and is "set" or shifted across the carriage by the handle, k. The scale, l, indicates the distance between the uprights and the saw. The foot lever, m, brings into action a device that "backs" the set beam to take on a new log while the carriage is gigging.

Gang Saw.—The gang saw, for cutting logs into lumber, constitutes an exception to the general rule that reciprocating tools are not used in woodworking machinery. Aside from the fact that it is one of the oldest types of saw used in this connection, the features that especially commend it are narrow saw blades, ability to cut up a log completely in one operation, without occasioning loss of time in gigging, and possibility of direct connection to a steam engine. The gang saw consists of a heavy vertical frame in which a saw-bearing sash slides rapidly up and down. A number of parallel saw blades are stretched between the top and the bottom girts of the sash, and since they are under tension only they can be made very thin. The cut is taken on the down stroke, and the teeth are drawn back slightly on the up stroke in order that they may not drag; this backward motion is given by a device which oscillates the lower end of the sash. Feed rolls (two above and

two below the work) carry the logs through the frame, and deliver the rough-cut lumber on the out-feeding side.

Power Consumption of Saws.—The power consumption of saws varies greatly according to the coarseness of the teeth, width and depth of cut, and rate of feed. The usual cutting speed is 10,000 feet a minute. With hand feed 3 to 5 horsepower is required. Heavy power-fed saw benches take 10 to 20 horsepower, and feed from 20 to 150 feet a minute; log mills require 25 to 50 horsepower, and the feeds range from 50 to 300 feet a minute.

Planers, Surfacers, Moulders and Shapers.—On account of vibration, fast cutting speed and feed, and the fact that a rip-saw tooth cuts only on the front and tears on the side, all rip-sawed surfaces must be planed by being passed over a rapidly revolving cylinder carrying two or more thin knives, which make a series of light, broad cuts as nearly parallel to the grain as possible. The knives must be longer than the width of the surface to be planed, and the feed and the cutting speed must be so related that no visible corrugations will be produced. Irregular surfaces may be obtained by varying the contour of the knife-edges—in every case the surface will be a counterpart of their contour. By the process just described, flooring is matched and beaded, and mouldings are made.

The hand planer, Figure 166, consists of the box frame, a, front and rear carriages, b and c, front and rear tables, d and e, and cutter-head or cylinder, f. A section of one of these cylinders in a somewhat

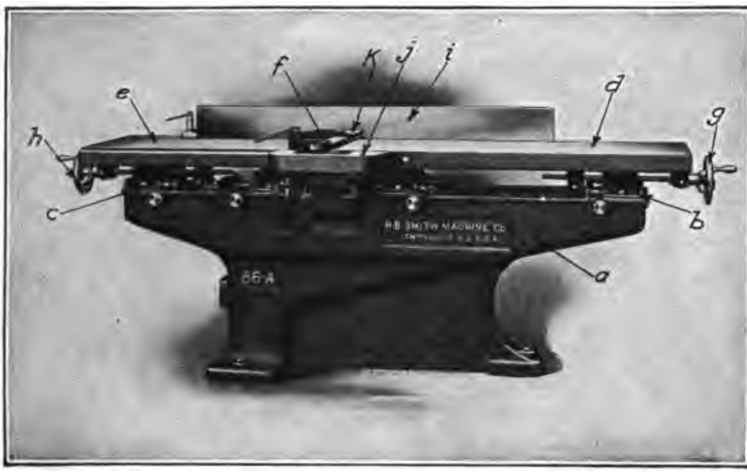


FIG. 166. HAND PLANER
H. B. Smith Machine Co.

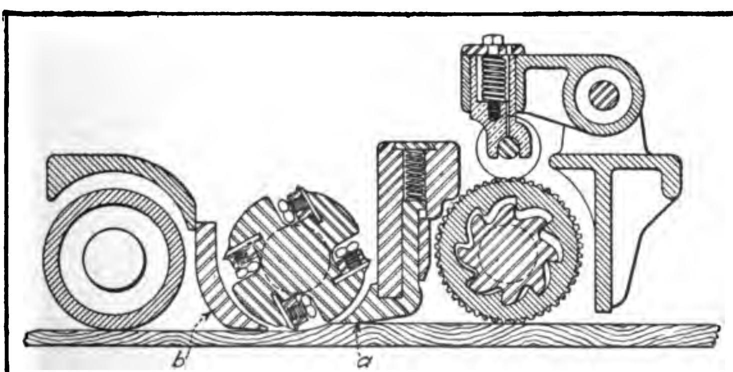


FIG. 167. SECTION OF A SURFACER HEAD

different machine is shown in Figure 167. Either table may be raised or lowered for cuts of different thicknesses by a turning of the hand wheel g or h, as the case may be, which slides it over inclines on the carriage. The adjustable fence, i, acts as a guide for the work; the bracket, j, which is ordinarily removed or swung downward, is used when work is to be rabbeted.

It was customary to use on early planers a cutter-head of rectangular section, with a knife bolted to each face. Necessarily there was much clearance between head and table, so that operators frequently lost some of their fingers in feeding the tail end of a board over the knives. Today circular cutter-heads with inserted knives are used on all hand-feed planers, and a guard, k (Figure 166), is set directly over the cutters.

For planing long boards in quantities a power feed is required. The cutter-head is mounted on an extension about ten inches above the table. Two feed rolls, also, are mounted on this extension, one in front of the cutter-head and the other behind it. The feeding-in roll is fluted, and so supported as to have considerable vertical play to allow for unevenness in the rough stock. Directly under the feed rolls are two other rolls, which work through slots in the table. The table is in one piece, and can be raised or lowered so that varying thicknesses of stock and depths of cut can be obtained. Front- and back-pressure bars—a and b, Figure 167—hold the stock firmly to the table immediately before and after it passes the cutters. A machine of this type is called a single-

cylinder surfacer. If another cutter-head is added, it is possible to surface both the upper and the lower side of a board at the same time; a machine that has this extra cutter-head is called a double-cylinder surfacer.

The efficiency of these machines is still further increased by the use of sectionalized feeding-in rolls and pressure bars, each section being pressed down independently by a weight or spring device (see Figure 167). A number of narrow boards which are twisted, or which have slightly different thicknesses, can then be fed simultaneously, and the full width of the machine can be utilized. In a double-cylinder surfacer, the upper cutter-head is placed ahead of the lower one, so that the stock has a firm support as it passes each head. The table can be raised or lowered for different thicknesses of material and varying cuts of the upper head; while the lower head, carried in the table, can be raised or lowered independently to vary the cut on the under side of the work. On all except the smallest of these machines, a rapid adjustment of the table-elevating mechanism can be made by power.

For cutting mouldings, hexagons, full and sectional rounds, and other strips of irregular cross-section, one or two vertical cutter-heads are desirable in addition to the horizontal heads of the surfacer. A machine that has these additional attachments is called a moulder. There are two distinct styles: the outside type, in which the table is supported in vertical slides on the side of the frame; and the inside type, in which the table is supported as it is in a

surfacer. The outside moulder is not rigid enough to be used for wide work, but it is more accessible than the inside moulder, on account of the more open construction. In both types, the vertical, or "matcher," heads have vertical, transverse, and swiveling adjustments, and the feeding-out rolls are dispensed with.

Figure 168 shows a six-head planer or matcher specially adapted for finishing boards simultaneously on all sides, and used in the manufacture of matched flooring. The lower cutter spindle, a, has a slight vertical adjustment to compensate for wear of knives, while the upper spindle and pressure bars can be raised and lowered on the guides, b. The table consists of a feeding-in extension, c, with adjustable fence for lining up the rough stock, and a platen which supports the work under the top cutter-head.

On some machines the platen and the lower feeding-in rolls have a wedge adjustment for raising and lowering them slightly, so that the thickness of the upper and the lower cuts can be varied without changing the thickness of the finished piece. A machine of this type is said to have a "wedge platen." The four feeding-in roll centers are at d, and the two feeding-out rolls at e. These rolls give a positive feed, and yet permit a wide variation in the thickness of stock. The side, or matcher, heads are located at f. In the illustration one of the driving spindles may be seen through a hole in the frame below; the two heads at the left end are used for beading and for other narrow cuts.

The power consumption of machines of the planer

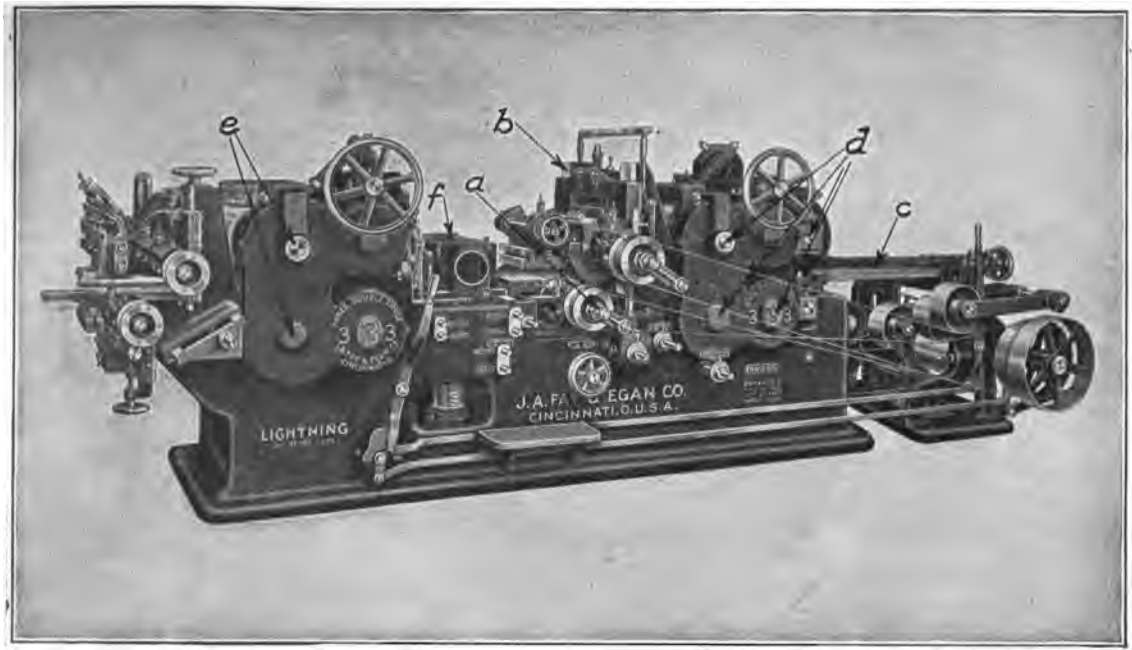


FIG. 168. SIX-HEAD PLANER OR MATCHER
J. A. Fay & Egan Co.

type varies with the feed, width, and depth of cut, and with the number of cutter-heads. Hand planers require 1 to 7½ horsepower, single-cylinder surfacers 5 to 20, double-cylinder surfacers 15 to 25, and four- and six-head machines up to 40 horsepower. These figures are for the usual feeds of 20 to 60 feet a minute; "fast-feed" machines, with feeds up to 250 feet a minute, require up to 60 horsepower. The usual cutting speed for planers is 5000 feet a minute.

For curved work, such as brush backs, and handles for hand saws, planes, and so on, a vertical spindle machine with hand feed is desirable. In the variety moulder or shaper, Figure 169, each spindle has an independent vertical adjustment for varying the height of the cut, and can be depressed entirely below the table so as not to interfere with large work. Ordinarily the shaper has a solid fixed table; but when it is necessary to cut profiles—such as column flutings—at some height from the table, the front half can be dropped, as shown, and the work can be suppported on the lower level.

Lathes.—For general manufacturing the lathe is much less useful than the planer and the moulder; it cannot attain the high cutting speeds of the planer without causing excessive vibration of the work, and is only useful for producing cylindrical and other surfaces of revolution, whereas the planers and the moulders can be used for both plane and cylindrical surfaces. The best work for the wood-turning lathe is pattern-making, the turning of table legs, stair balusters, and pieces of varying diameter, and the manufacturing of elliptical and irregularly curved

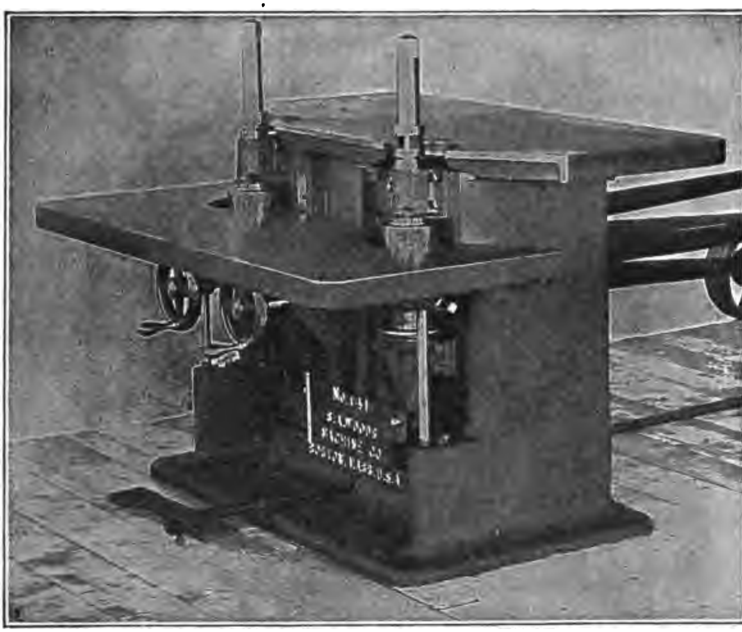


FIG. 169. DROP TABLE MOLDER
S. A. Woods Machine Co.

articles, such as hammer handles, wagon-wheel spokes, gun stocks, and so on.

For plain turning, a light "speed lathe" is used, with bed, legs, headstock, and tailstock like those of an engine lathe. No back gears are necessary, for sufficient speed variation is obtained by means of a three-stepped cone pulley. The live spindle is threaded to receive a face plate, and is reamed to take a three-pronged spur center for driving long work that must be supported at both ends. The tool is usually held against an adjustable rest and fed

by hand; but for accurate pattern making, tool carriages are provided, as in engine lathes. Face lathes, consisting of a headstock mounted on a suitable base, with tool rest carried on a bracket, are used for turning patterns of wheels, pulleys, cylinder covers, and the like. The tools commonly used for these lathes are the gouge (for roughing), skew, round-nose and straight chisels, and the parting tool.

Gauge Lathe.—The gauge lathe is used for turning table legs and other irregular surfaces of revolution. The irregular contour is obtained with a roughing tool, which follows a fixed template, or former, secured to the bed. A finishing cut is taken by a formed "back knife," mounted obliquely in a frame which slides in two vertical guides so that the knife is always in contact with the work just behind the roughing tool. If the former is rotated at the same speed as that of the work, still more irregular shapes can be turned, which need not be surfaces of revolution.

Blanchard, or Copying, Lathe.—Figure 170 shows a Blanchard, or copying, lathe, used for turning these irregular forms. The essential parts are: the main frame, shaped roughly like that of a speed lathe; and the carriage, a, which travels on the ways of the bed and supports a revolving cutter-head, b. A vibrator frame, c, carries a former or pattern, d, revolving between centers, e, e, and the stock (not shown) between the centers, f, f. The vibrator is supported in bearings in the lower part of the main frame, and is oscillated backward and forward by the irregular pattern, which rotates between the shoe, g, on the

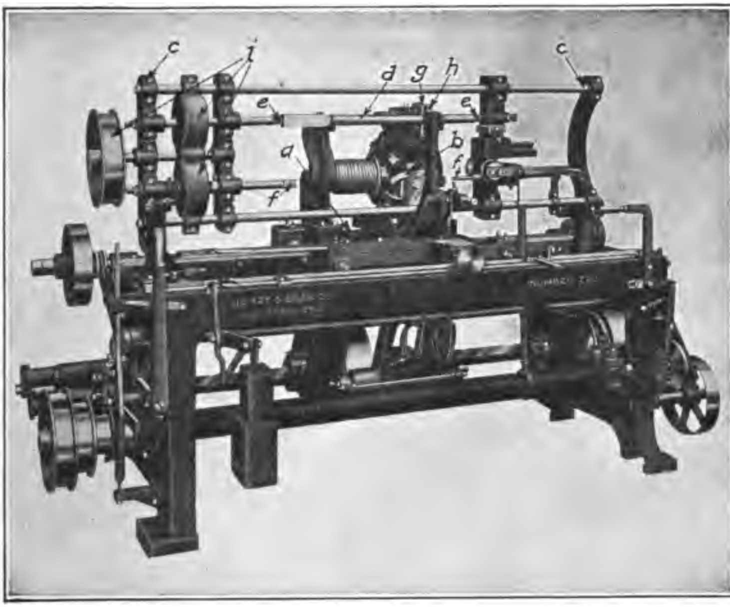


FIG. 170. BLANCHARD OR COPYING LATHE
J. A. Fay & Egan Co.

carriage, and the shoe, h, on a pivoted arm. As the stock and the former are carried in the oscillating frame and are rotated in the same direction and at the same speed by means of the drive, i, the cutter-head will reproduce in the work the shape of the pattern above it. A lead screw feeds the carriage along the bed until the end of the work is reached, when the pressure of the shoes is automatically released and the carriage is returned at high speed to its starting position. The pattern and the work can be rotated between fixed centers and the cutter-head and shoe can be carried on the oscillating frame; this

arrangement is utilized in other types of the Blanchard lathe.

Miscellaneous Machines.—In the manufacture of doors, windows, cars, and framed articles, the borer and the mortiser are used for making round and rectangular holes. The single-spindle borer resembles the plain drill press for metal drilling, except that a hand feed is always used and the table usually has a universal adjustment for positioning, or else is fitted with rollers for handling long timbers. The most satisfactory mortiser is the hollow-chisel type, illustrated in Figure 171. The cutting tool, a, is a square hollow chisel which trims the sides of the mortise, inside of which a bit rotates and clears out the material. The tool is fastened to the plunger, b, which has a power feed with quick return and an adjustable travel controlled by the dogs, c, c. The bit spindle is carried in bearings in the plunger, and is driven by a belt passing to the main pulley, e, over the idlers, d, d, which automatically maintain tension in the belt, irrespective of the position of the spindle pulley inside the plunger head.

The carriage, f, in which the plunger slides, has a forward adjustment on the frame, and the table, g, has vertical and longitudinal adjustments, all operated by hand wheels, for setting the work and varying the depth of mortise. The vise, h, is specially designed to hold down the work while the chisel is rising. Unlike the old-style mortisers, which were simply machine-operated chisels, this machine finishes the hole in one stroke downward.

The wood-milling machine (Figure 172), is a recent

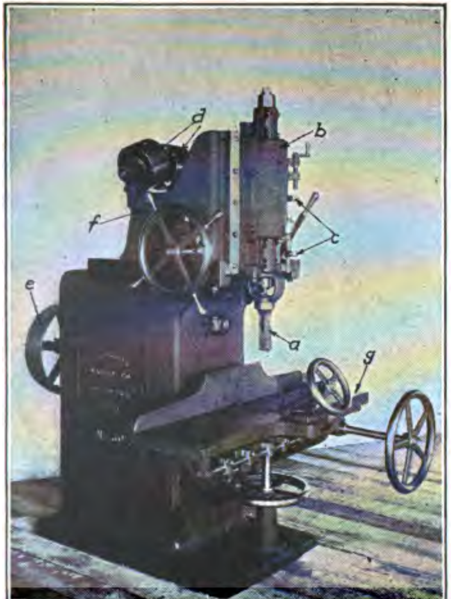


FIG. 171. HOLLOW CHISEL MORTISER
S. A. Woods Machine Co.

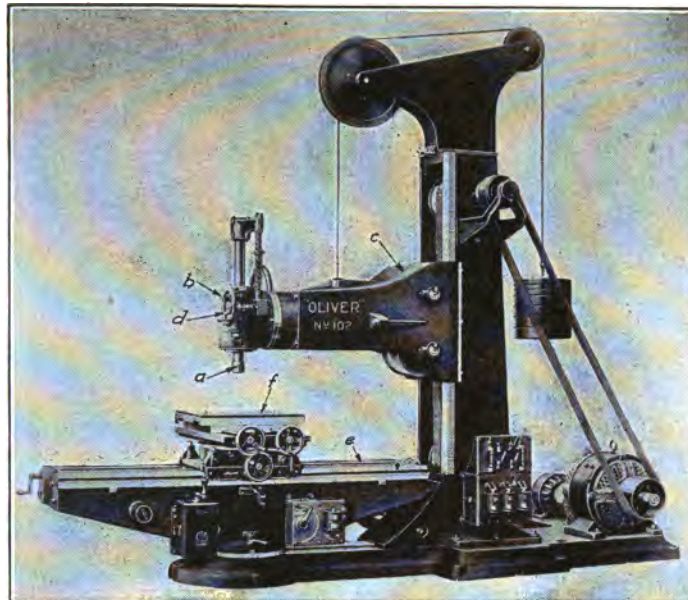


FIG. 172. WOOD MILLING MACHINE
Oliver Machinery Co.

development in pattern-shop equipment. Like the universal miller for metal-working, it is not a manufacturing machine, but it can produce an almost unlimited variety of shapes with the accuracy of a machine tool. It corresponds in general design to the vertical die-sinker, Figure 107. The spindle, a, is carried by a head, b, at the end of an adjustable counterbalanced arm, c; the head swivels 90 degrees to the right and 45 degrees to the left, and the spindle has a short vertical travel independent of the arm, controlled by the hand wheel, d. The main bed, e, swivels to any angle desired, and supports a carriage on which is mounted a table, f, which can be swiveled and adjusted transversely or longitudinally by the hand wheels shown. Graduated scales are provided for facilitating accurate adjustments, and the carriage can be fed along the bed by either hand or power. This machine is very useful in making core boxes, gear patterns, and other complicated shapes. Other wood millers are constructed along simpler lines; they have a horizontal and a vertical spindle mounted directly in the column, with the table supported in a knee sliding in vertical ways on the front of the column.

Sanding machines are used for finishing woodwork when a planed or a turned surface is not sufficient. In these, the cutting element consists of discs, drums, or cloth belts covered with sandpaper, against which the work is held until ground smooth and to shape. Usually the work rests on a table provided for the purpose, and is fed by hand. An important exception is the multiple-drum sander, in which rotating and

oscillating sanding drums polish the under surface of the work as it slides along the table under the action of feed rolls, which bear down on its upper surface.

CHAPTER XXIV

PAPER MACHINERY

Rag Machinery.—The striking characteristics of paper machinery are: large power consumption in comparison with the amount of labor employed; and the use of water and steam in enormous quantities, the first as a carrier for the paper fibres, and the second for cooking and drying. Census figures show that about 17 horsepower per wage-earner is consumed in paper and pulp manufacture; in steel manufacture and rolling only about half that amount is used, while in typical machine shops only 2 or 3 horsepower per wage-earner is employed. The amount of water used is indicated by the fact that for every ton of paper produced, from 12,000 to 100,000 gallons of water are needed for such processes as washing and diluting, in addition to which 10,000 to 15,000 gallons must be used in the form of steam.

The principal machinery and apparatus required in the manufacture of paper, is as follows:

For converting rags into "half stock": threshers, rag-cutters, dusters, digesters, washers.

For converting wood into "half stock": barkers, grinders, chipping machines, digesters for soda or sulphite process.

For preparing the wet pulp or "stuff": beaters, refiners.

For making machine-finished paper: Fourdrinier or cylinder machine, including winders and one or more calenders.

For cutting and finishing: slitters, cutters, super-calenders, plating and glazing rolls, coating machines.

Auxiliary apparatus: belt conveyors, triplex and centrifugal pumps, blowers, exhausters, and so on.

Dusters and Cutters.—The purpose of rag machinery is twofold: to remove loose dust, and to cut the rags into small pieces. The thresher, which performs the first of these duties, consists of a tightly built wooden chest, about eight feet high and ten feet long, with a side door through which the rags are charged; a wooden cylinder that extends lengthwise through it, is provided with arms or beaters projecting radially from its surface, and driven by a pulley at one end of the shaft. The cylinder stirs up, pokes, and pulls out the lumpy rags as they come from the bale, while suction ducts connected to the upper part of the machine draw off the loose dust. The "devil" works on the same principle; its shape is more or less cylindrical, instead of rectangular, and the revolving beaters are aided by stationary beaters fixed on the inside of the casing.

There are two types of duster. In the railroad duster, from three to six revolving cylinders are set in a row, each covered with hard-wood lagging, and fitted with projecting steel pins which pass between other sets of pins projecting inwardly from the casing. These pins beat and thresh the rags as they

FIG. 173. TAYLOR DUSTER

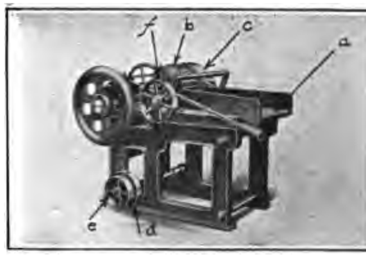


FIG. 174. RAG CUTTER
Holyoke Machine Co.

travel from the feeding hopper to the discharge end of the machine, while the dust is sucked out as in the case of the thresher. The other type, illustrated by the Taylor duster, Figure 173, is of about the same size and shape as a thresher. Inside the chest there is a screen consisting of one or two skeleton cylinders, covered with quarter-inch mesh wire cloth rotated by the pulley, a; there is also a central shaft, fitted with propeller blades and driven in the opposite direction by the pulley, b. The rags are fed into the right-hand end of the screen, and as they are driven through to the left-hand end by the screw action of the blades, they are tossed about and dragged over the screen, being thereby freed of all remaining loose dirt, buttons, hooks, and so on. Machines of the usual size can handle about three hundred pounds of rags an hour, and a series consisting of one thresher, one railroad duster, and two screen dusters, will remove from 2 to 10 per cent of the weight of the stock in the form of dust.

Figure 174 shows a medium-sized rag-cutter for cutting threshed rags into strips an inch or less wide. The rags are fed by hand or by a belt con-

veyor into the trough, a, passing under the toothed feed-roll, b, to a series of revolving knives acting against a fixed knife, as in a lawn mower; these knives cut them, and then they are dropped on to a discharging conveyor (not shown in the figure). The driving pulley, c, is attached directly to the shaft carrying the knives, the feed roll being driven by an open belt running from the knife shaft to pulley, d, and by a crossed belt from pulley e to pulley f; these, together with the gearing shown, give a large reduction in speed. The feed roll does not run in fixed bearings, but rides on the surface of the rags, having sufficient weight to seize them with its teeth.

Digesters and Washers.—The digester or boiler for saponifying the glutinous and resinous substances in rag stock and washing out the last of the dust, is a spherical or cylindrical steel tank, built to stand forty to fifty pounds of pressure. It is fitted with a door for charging and discharging the stock, a pipe for supplying steam, another for letting in the wash liquor, and one or more blow-off cocks. It may be stationary or revolving; in the former case, the lower part forms a reservoir for liquor, above which is a perforated plate on which the stock rests. Steam is admitted at the bottom, and circulates the liquor by blowing it up through a central pipe to a spray-head near the top of the boiler, from which it is squirted down over the rags, somewhat as coffee is distributed in a percolator.

Revolving boilers are supported in trunnions, and are rotated slowly by worm or double-reduction spur gearing. One trunnion forms an inlet for steam, the

other for liquor. The capacities of these boilers vary from 2 to 6 tons of rags. Spherical ones, which rarely exceed 10 feet in diameter, have the smallest capacity; cylindrical ones range in size up to 25 feet in length and 10 feet in diameter, and hold a correspondingly greater weight of stock. The steam pressure, weight of liquor, and length of boil vary according to the chemicals used and the quality of the stock; caustic soda requires approximately only half the pressure, length of boil, and chemical per pound of stock that caustic lime demands.

A washer, or Hollander, as it is frequently called, because of its invention in Holland, is used for removing the dirt and coloring matter dissolved from the rags in the digesters, and breaking the rags up into small clumps or knots of fibre, which are still further subdivided in later operations. As seen in Figure 175, the washer consists of an oval-shaped tub, about 20 feet long, 9 feet wide, and 3 feet high, with a partition or "midfeather" dividing it into two parts for two-thirds of its length. A roll faced with blunt steel or bronze knives, called the breaker roll, rotates in one part under the semi-cylindrical hood, and one or more wash drums (not visible in the illustration) covered with wire cloth, rotate in the other part. Both roll and drums have their bearings adjustable in vertical slides, so that their depth of immersion can be varied.

The floor of the tub is smooth and level, except in three places: the "breast," directly in front of the breaker roll, where it slopes up slightly; under the roll, where it supports a plate carrying 6 or 8 knives

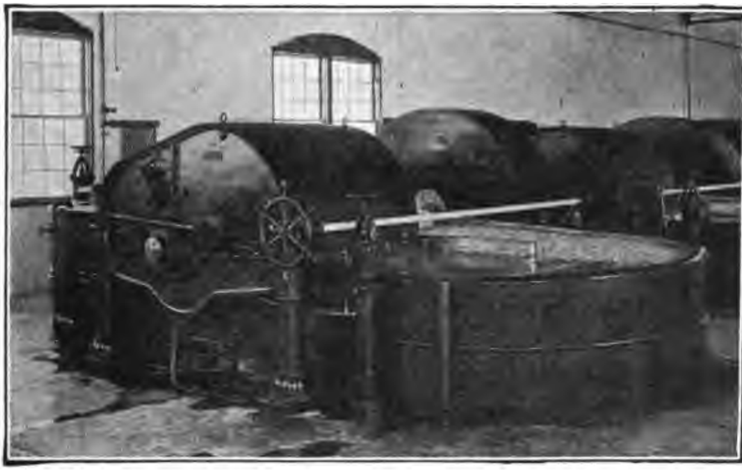


FIG. 175. WASHER
E. D. Jones & Sons Co.

like those on the roll; and behind the roll, where it rises in a curve close to the circumference of the roll, and then slopes down to its normal level—the "back-fall," as it is termed. In operation, the washer is filled with boiled rag stock and water, and the breaker roll paddles the mixture over the back-fall to the wash drums and back again for two to six hours. The fibres are torn apart and brushed lengthwise—not cut—as they pass between the knives of the roll and floor plate, which are brought closer together as the stock becomes more subdivided; at the same time, dirty water escapes to the interior of the wash drum, from which it is withdrawn through one of the bearings either by dippers or by a siphon.

Wood-Pulp Machinery.—Wood pulp is of three principal kinds: mechanical, soda, and sulphite, each of which requires special machinery. Mechanical pulp, which is simply finely ground wood fibre, is made in a grinder, an example of which is shown in Figure 176. This is an emery or sandstone wheel rotating on a horizontal shaft within the casing, a. Three or more pockets, b, with doors, are built into the casing, over each of which is mounted a hydraulic cylinder, c, whose plunger moves radially in relation to the wheel. The logs to be ground are cut into two-foot lengths, barked in machines (described in the next paragraph), split into boards, and freed as far as possible from knots. These boards are then set in the pockets and pressed by the plunger against the rotating stone, which slowly wears them away. A stream of water keeps the wood from burning, and at the same time washes away the pulp which varies greatly in quality according to the amount of water used. As can be imagined, the friction of these machines consumes a great quantity of power; for example, a 6-pocket grinder with a wheel whose surface speed is 3000 feet per minute, requires 1200 horsepower.

Barkers and chippers are required for preparing logs for the soda and sulphite processes. These machines differ with respect to the method of feeding the logs. In both cases, knives are mounted on the face of an inclosed disc, about 5 feet in diameter, rotating on a horizontal shaft. The casing with its discharge spout for bark and chips, has the appearance of a centrifugal pump. The barker has a device

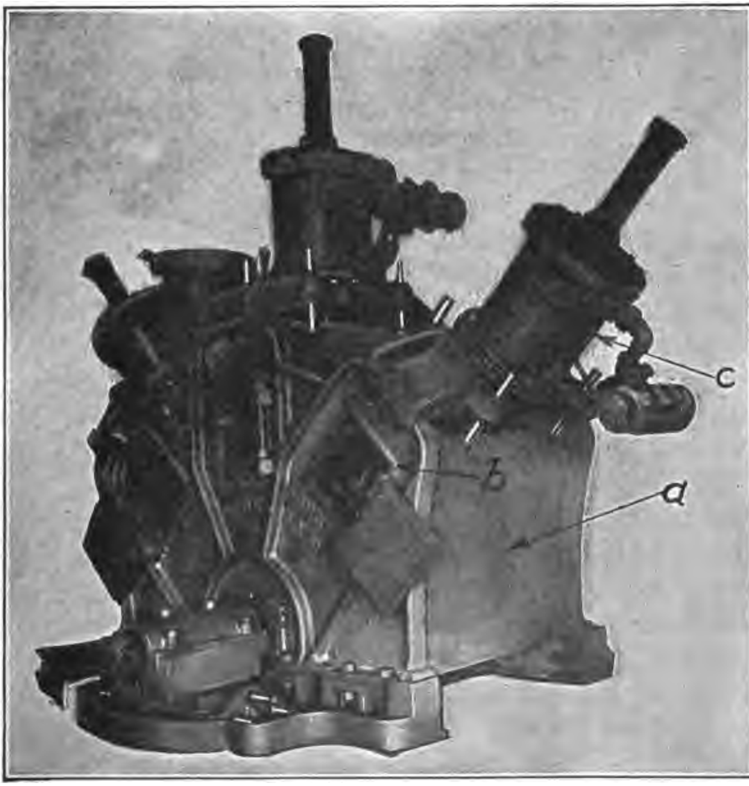


FIG. 176. WOOD PULP GRINDER
The Bagley & Sewall Co.

on one side which holds the logs (cut to short length, as in the mechanical pulp process) in a horizontal position and forces them against the knives, rolling them over at the same time until the bark is completely sheared off. The chipper has an inclined chute, through which the logs are fed end on; in this case, the knives break them up into small chips

with an action which corresponds to the blow of an axe in felling a tree.

The digesters for soda pulp are like those used for rag stock. The capacities are much greater, however, and the steam pressure higher; 20 tons of chips are a usual charge, and require 8 to 10 hours boiling at a 100-pound pressure. The sulphite pulp-digester must be lined with lead, brick, or cement, because of the corrosive sulphurous acid that the liquor contains. It is built vertically, about 8 feet in diameter and 45 feet high, and is arranged either to admit steam directly to the liquor at an 80-pound pressure for the rapid process, or to circulate the steam through pipe coils at a 45-pound pressure for the slow process. The sulphite digester requires ovens for burning sulphur with a deficient supply of air. The acid calcium sulphite solution is formed in wooden towers charged with broken limestone which is converted by a current of sulphur dioxide, led in at the base, and a counter-current of water sprayed down from the top.

A series of riffles, cr "sand traps," followed by strainers removes knots and pieces of undigested wood from the "half-stuff" produced in the digesters. The stuff is then pumped to the beaters cr, if it is to be shipped to another mill, is concentrated and made into soft, thick sheets of "air-dry" pulp. The "slusher," used for the concentrating, is a wooden vat with a partition dividing it into a large and a small part; a cylinder covered with wire cloth rotates in the large part, picks up a coating of fibre from the dilute stuff which surrounds it, and trans-

fers this fibre to a felt-covered roll, from which it is scraped into the small compartment of the vat holding the concentrated material.

Beaters and Refiners.—The half stock and the air-dry pulp are mixed in the proper proportions and prepared for the paper machine in a beater, the function of which is to separate the fibres and draw them out to their extreme length without cutting them. This machine is like the washer for rag stock, previously described; the chief differences are the finer vertical adjustment of the beater roll, the omission of wash drums, and the grouping of the roll knives in sets of three or more with wide space between the sets to make the roll more efficient as a paddle wheel for the stuff, which is much more dilute than in the washer. Sharp knives are used to produce "free" or "fast" stock suitable for filter, duplicating, blotting, and news-print papers; medium blunt knives for turning out high-grade writing and print paper, and very blunt ones for the production of bond, strong wrappings, and so on, requiring "greasy" stock. In the latter case, stone floor plates opposite the knives are sometimes used.

The capacities of the beaters vary widely. Medium sizes are about 16 feet long, 8 feet wide, and 3 feet deep, with a roll 3½ feet in diameter, and hold the equivalent of 500 pounds of air-dry pulp; the largest sizes hold from 2000 to 3000 pounds. In all cases, the circumferential speed of the roll is about 2000 feet a minute. The power consumption per ton of stuff diminishes as the size of beater increases; it also varies greatly with the clearance between roll

and bed plate, and with rate of circulation of the stuff, $2\frac{1}{2}$ horsepower per 100 pounds of dry stuff being a fair average.

The operation of refining or brushing out the fibres straight and parallel, may be performed on the beater by raising the roll shortly before emptying. In the case of high-grade paper, however, this operation is done in a Jordan or Marshall refiner, which consists of a conical drum carrying longitudinal beater knives revolving inside a conical shell, with corresponding knives set on its inner surface. The clearance between stationary and rotating knives, varied by sliding the drum longitudinally, is just sufficient to give the desired brushing action to the fibres as the stuff flows through from the small to the large end of the cone.

Paper Machines.—By far the greatest tonnage of paper is produced on the Fourdrinier machine, invented and patented by a French paper-maker, Louis Robert, in 1799, and perfected some years later by Henry and Sealy Fourdrinier, the proprietors of an English paper mill. The machine has undergone no fundamental changes, but has been improved in details to increase the size, speed, flexibility of drive, recovery of stock from the waste water, and safety of the operators.

A typical machine is shown in elevation in Figure 177, and in plan in Figure 178. It consists of a "wet end," on which the paper is formed, two or three pairs of press rolls, which reduce it to the correct thickness, a series of drying rolls, one to six stacks of calenders, and one or more reels on which

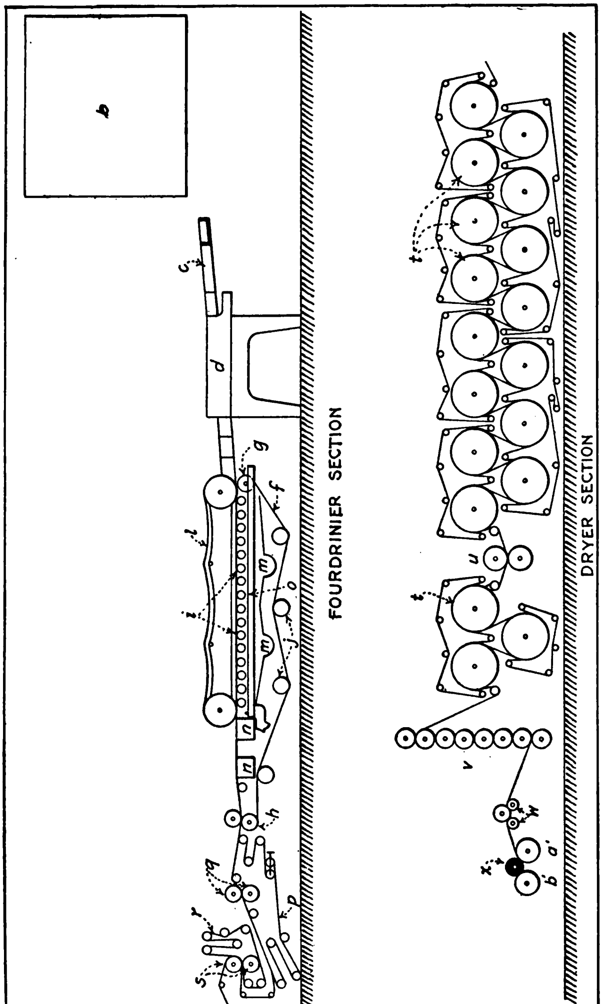


FIG. 177. ELEVATION OF A FOURDRINIER PAPER MACHINE

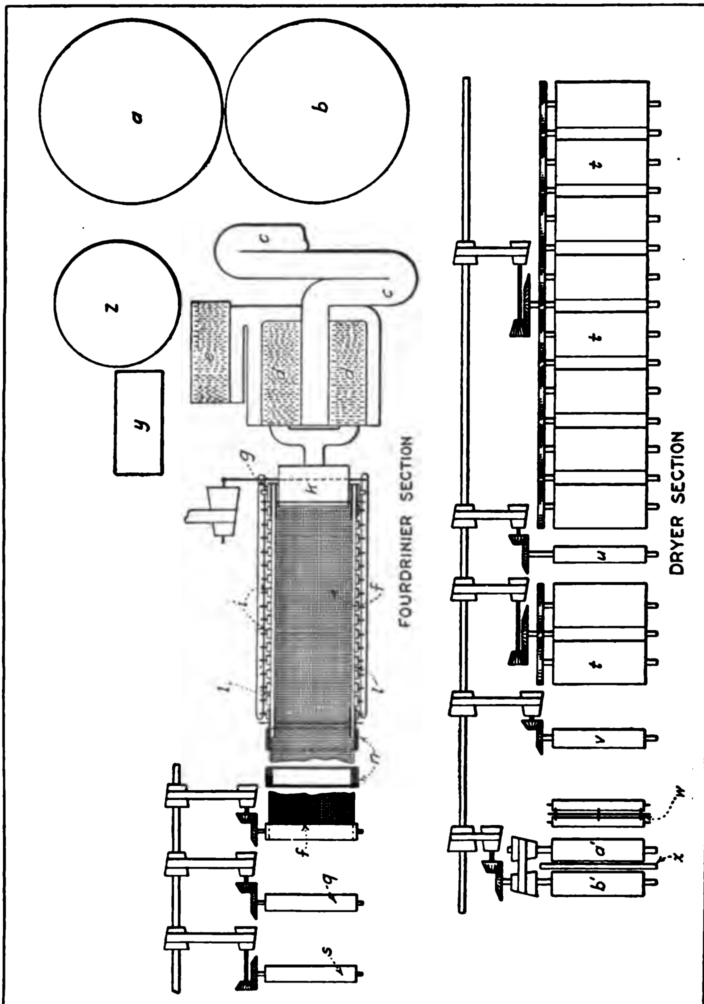


FIG. 178. PLAN OF A FOURDRINIER MACHINE

the machine-finished paper is wound. The pulp flows from the beaters to the stuff chests, a and b. Figure 178, where it is kept from settling by paddles attached to vertical rotating shafts. It is then pumped to a regulating box (not shown), in which it is diluted to its final consistency and maintained at a constant level by means of an overflow pipe, which assures a constant flow into the machine. From here it passes through a regulating cock to the sand tables, a series of long, narrow, inclined troughs covered on the bottom with long-haired felt or with strips of wood set at 45 degrees, which catch any coarse solid particles, as well as sand and dirt that have not yet been separated from the fibre. The lower end of these sand tables appears at c.

The pulp then flows to the strainers, d, d, to remove knots and intertwined fibres. The usual type of strainer has a flat plate, about 7 feet long and 2½ feet wide, pierced with fine slits 2 to 3 inches long, a quarter-inch apart, and less than 0.05 inch wide, which allow only individual fibres to pass through. In order that the action may be more rapid, the plate is jogged up and down by a crank and pitman, or else a vibrating diaphragm in the trough under the plate produces an alternating puffing and suction action. Other types of strainers have revolving or oscillating cylinders instead of flat plates.

The pulp that fails to pass the strainers, d, d, is washed off to the auxiliary strainer, e, and all that passes this one is returned to the regulating boxes for dilution with fresh stuff. That which passes the main strainer is led directly to the "wire" of the

machine. This is an endless sheet of wire cloth, f (Figures 177 and 178), 30 to 50 feet long and 100 to 250 inches wide, woven with about 70 strands per inch, and passing from the breast roll, g, to the lower couch roll, h, and back again. On its forward travel it is supported by a number of small rolls, i, set close together, returning over and under the rolls j, whose position can be adjusted so that they will regulate the tension of the wire.

The stuff is fed to the wire on an apron of rubber or waterproof cloth, k, whose edges are folded up to keep the pulp from overflowing, and is spread evenly to the proper thickness by an adjustable gate, or "slice," at the point where it flows from the apron onto the wire. It is carried along by the wire, restrained on either side by the endless rubber bands, l, l, called deckle straps, while the water collecting in the meshes of the wire is carried off on the surface of the rolls by capillary action and passes into the troughs, m, m. Just before reaching the couch rolls, the wire runs over suction boxes, n, n, where a large amount of water is taken from the pulp by vacuum pumps. This, together with the water from the troughs m, m, and from the strainer, e, drains into the low-box, y, from which it is pumped to the high-box, z, for dilution with fresh pulp.

The watermark, if one is desired, is produced between the suction boxes by a light wire skeleton cylinder called a "dandy roll," having the pattern in raised wires on its surface which rests on the surface of the paper. From the breast roll to the first suction box, the wire, the deckle straps, and the sup-

porting rolls are all carried on the deckle frame, o, which is hinged at the left-hand end to a fixed part of the machine and is given a rapid sidewise "shake" at the right-hand end, with the object of thoroughly interlacing the fibres as they are formed into a web of paper. This action is the essential characteristic of the Fourdrinier machine.

The moist paper leaves the wire at the couch rolls, and is immediately picked up by an endless sheet of felt, p, which carries it through the first press rolls, q, q, after which it is turned over and picked up by another felt, r, and carried through the second press rolls, s, s. Thus each side of the paper comes into direct contact with a roll and is smoothed by it. From this point the web passes up and down over steam-heated drying rolls, t, from sixteen to forty in number, being held in close contact by the felts shown in the figure. The pair of steam-heated smoothing rolls, u, u, of polished chilled iron, give the paper a preliminary calendering. The machine is often arranged for sizing by interposing between two batteries of dryers a tank of sizing material into which the paper is passed.

The calender, v, at the left of the dryers, puts the "machine finish" on the web of paper. Pressure is applied by screws or by weights and levers; the paper passes progressively between each roll and the next lower one, and under the combined action of pressure and steam heat is compressed and given a smooth, hard surface. Any number of calenders may be installed in series, the number depending upon the grade of finish desired. The web is finally

trimmed on the edges and slit to the desired widths by rotating disc knives, w; then it is wound on the reel, x.

Figure 178 shows a typical power drive for a Fourdrinier machine. The shake, couch roll, press rolls, first and second drying batteries, smoothers, calender, and reel, are driven separately from the main shaft by the cone pulleys and bevel gears shown in the figure; thus is secured the independent speed regulation necessary for counteracting irregularities in the shrinkage of the paper as it dries. The power consumption of medium-sized machines from breast roll to reel with the driving mechanism, is about 8 horsepower per ton of paper per 24 hours. To this figure must be added 50 per cent for stuff-pumps, strainers, and other auxiliaries. The tendency is to make wider machines; whereas 150 inches was about the maximum a few years ago, wires over 200 inches wide are in operation today. At the same time speeds have increased; at present a wire speed of 250 feet a minute is a fair average, and 700 feet is the upper limit, though that will doubtless be exceeded in the near future. These wide, fast machines require much more power than the amount mentioned above.

A modified form of Fourdrinier, known as the single-cylinder machine, is sometimes used for very thin paper, or paper to be finished on one side only. The distinguishing feature is a single drying cylinder about 10 feet in diameter, in the place of the battery of smaller cylinders, t, on the Fourdrinier. A machine which is similar in name, but entirely different

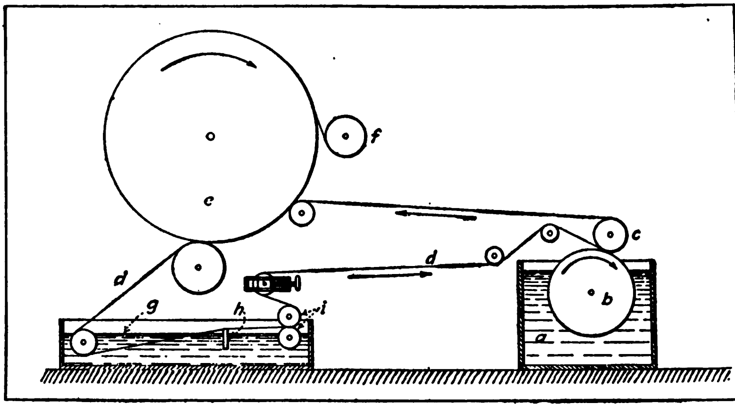


FIG. 179. CYLINDER PAPER MACHINE

in form—called a cylinder machine—is used for the manufacture of low-grade paper, mill board, and air-dry wood pulp. The strained pulp enters a tank, a, Figure 179, in which a skeleton cylinder, b, covered with wire cloth, revolves. The fibres stick to the wire while the water passes through the meshes, under the action of a suction pump; the sheet of paper thus formed is removed from the cylinder at the couch roll, c, by the felt, d, which carries it to the large steam-drying roll, e. After drying, it is wound off on the reel, f; the felt in the meantime returns to the couch roll through the washer, g, over the scraper, h, and between the squeezing rolls or wringers, i, i.

One cylinder cannot make a thick sheet, so that in the manufacture of heavy paper board a number of cylinders are mounted in tandem, the wet webs being taken off in successive layers on the same felt; it is thus possible to obtain different colors on opposite

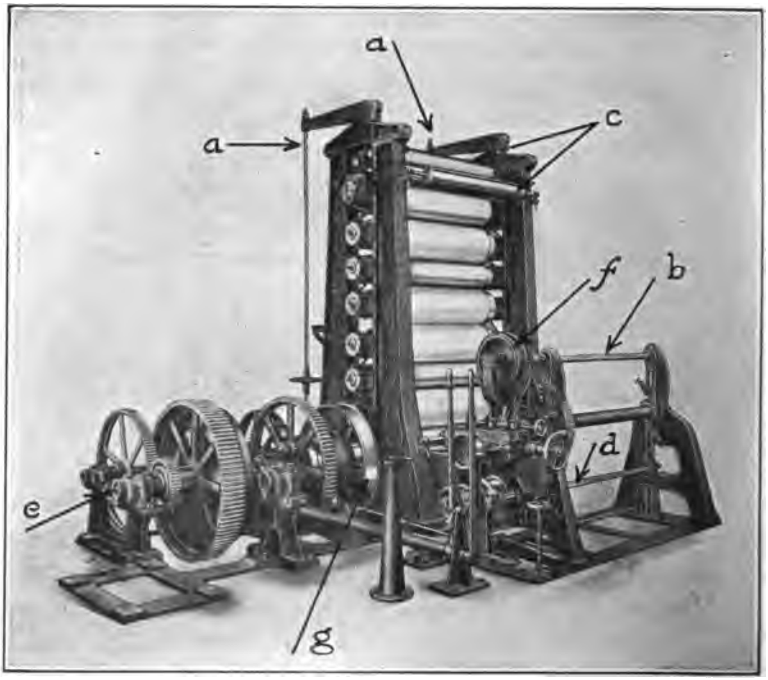


FIG. 180. SUPERCALENDER
Holyoke Machine Co.

sides of the same sheet. In a modification of this machine, the drying cylinder, e, is replaced by a pair of press rolls, and the wet web is wound on the upper roll until the required thickness has been obtained, when it is slit across from side to side, taken from the rolls, laid out flat, and dried in heated lofts.

Finishing Machinery.—A super-calender is used for obtaining a smoother surface than that which is called "machine finish." A typical machine of this kind is shown in Figure 180, which, with the omission

of the winding device, would represent an ordinary calender. The rolls are built up in stacks of four to twelve, compressed paper rolls alternating with chilled iron. Pressure is applied by means of levers and tension rods, a, connected to weights. A reel of dampened paper is placed at b, and the paper is fed over the guide rolls, c, to the top calender roll, and then back and forth between the rolls until it reaches the bottom; finally it is rewound at d. The drive is through the shaft, e, to the lowest roll, which can be driven directly or at a lower speed through back gears. The unwinding reel is held back by the brake, f, which keeps a uniform tension in the paper; and the winding reel, belt-driven from g, can be slowed down any desired degree as the roll of paper increases in diameter.

In contrast with this variable-speed reel, the constant-speed winder, Figs. 177 and 178, should be noted. In this case the power is applied to the rolls, a′, b′, instead of to the reel, and since the paper travels at constant speed, the reel, which simply rests on the rolls, will be rotated at the right speed whatever the amount of paper wound upon it. In order that the paper may be wound tightly, b′ is driven slightly faster than a′.

For plate glazing or linen finishing a special two-roll calender is used which is provided with horizontal front and back tables level with the top of the lower roll, and a reversing drive is employed. A stack of paper sheets, alternating with copper or zinc plates or sheets of linen, is set on the front table and passed back and forth between the rolls until the

surfaces are sufficiently finished. Friction glazing is done on a two- or three-roll calender in which one of the rolls is driven much faster than the others by a special spur-and-pinion connection.

The most highly finished paper is made by coating with a mixture of china clay and thin glue. The apparatus for this process varies in details, but always has these principal parts: a vat for holding the coating fluid; brushes for working out lumps and smoothing the coated surface; an automatic carrier for conveying the coated paper through the drying room; and glazing calenders. The body paper is passed through the vat, between two press rolls which remove the excess coating, and then between two sets of brushes, one above and one below, which vibrate across the paper. Each set consists of a coarse, a medium, and a fine brush—the last usually camel's hair—working in series on the web of paper. After leaving the last brushes, the web is picked up at intervals of fifteen to twenty feet by cross bars, which rise toward the ceiling and then travel horizontally into the drying room. The web, therefore, hangs in festoons reaching nearly to the floor, and is dried without touching anything except the cross bars. After drying the web is reeled and run through calenders that polish the surface.

CHAPTER XXV

BOOT AND SHOE MACHINERY

General Characteristics.—The machines used in making boots and shoes are quite unlike those which are to be found in other lines of manufacture. The difference is due to the nature of the principal material used, to the small size of the parts composing the shoe, and to the kinds of operation performed. In general, shoe machines translate into mechanical processes the manual dexterity of the old-fashioned shoemaker in using the hammer, knife, awl, and needle. The fundamental machines, most of them developed by clever shoemakers, were original in design, and even those now used for pressing, rolling, grinding and buffing are distinctive, for they do not closely resemble the corresponding machinery in wood or metal-working, although they perform the same operations.

History of Shoe Machinery.—The first important shoe machine, which was invented in 1815, made wooden pegs for fastening the soles of shoes to the uppers. In 1845 the rolling machine was introduced, for compressing and hardening sole leather; this mechanical process replaced the hand hammering which had been in vogue up to that time. In 1851 a Lynn shoemaker, by the name of Nichols, adopted

Howe's sewing machine to sewing shoe uppers, and a year later the machine was used in the manufacture of shoes by John Wooldredge, also of Lynn. The introduction of this machine made shoe manufacture distinctly a factory industry. In 1858 Lyman R. Blake, another shoemaker, invented a machine for sewing uppers and soles together, which was improved by Mathies and built by Gordon McKay, a capitalist and manufacturer. It was first used commercially in 1861, and now the name McKay is given to one of the most widely manufactured types of shoe in this country.

A still more important advance was made in 1862, when Auguste Destouy, a New York mechanic, invented a machine with a curved needle for sewing the soles of turn shoes. This was developed under the direction of Charles Goodyear, son of the inventor of the vulcanizing process, and in 1875 was applied to the sewing of welts to insoles in the manufacture of "Goodyear welt" shoes, which are superior to all other types in comfort, wearing quality, and appearance. The manufacture of the rougher grades was made materially easier by the commercial application, in 1857, of a pegging machine for driving the wooden pegs that hold together the insole, upper, and outsole in pegged shoes.

The first successful lasting machine, the invention of a Boston lawyer, George Copeland, was exhibited at the Centennial Exposition, in 1876. A machine duplicating the hand method of lasting was invented in 1883 by Matzeliger, an expert machinist who came to Lynn from Dutch Guiana and learned the shoe

trade. These two machines eliminated the only remaining hand process in shoe manufacture: that of stretching the upper over the last and securing it temporarily by nails, until the sole was attached. These machines have been supplemented by the pulling-over machine, which prepares the shoe for lasting. A recent invention is the clicking machine, for cutting uppers from the hide or skin; it takes the place of the workman with his patterns and knife, who was known as the hand cutter.

Machine Operations.—The principal operations performed in shoe manufacture are: cutting, bending and stretching, and stitching. Among the machines for the first of these operations are clicking machines, stripping machines for cutting hides into strips of a width equal to the length of the sole, sole-cutting or "dieing-out" machines, splitting machines, channelers, skiving machines, edge setters, and so on. Some of these work on the principle of the punch, others use either rotary or stationary knives, while still others use revolving cutters similar to milling cutters. Some of the machines for the second class of operations are sole-laying and sole-leveling machines for bending the sole to the proper shape, channel-opening and channel-laying machines for raising and flattening the channels on insoles, and pulling-over and lasting machines for stretching the uppers over the lasts. The third group is made up of sewing machines of different types, some of which—such as the McKay sewing machine, the Goodyear welt, and the Goodyear outsole rapid-lockstitch machine—stand as landmarks in the development of shoe machinery.

Other operations performed by special machines are rolling, hammering, pressing, nailing, cementing, ironing, grinding, buffing and polishing.

Arrangement of a Shoe Factory.—The modern shoe factory is composed of six departments: for cutting, stitching, stock fitting, "making" or bottoming, finishing and treeing, and for packing and shipping. The cutting and stitching rooms are usually on the top floor, and the sole leather room is generally on the ground floor. The bottoming room is on the floor next below the cutting and stitching departments, and the shipping room is generally on the floor next above the sole-leather room.

Types of Shoes.—The methods now in use for fastening the upper to the sole are: (a) McKay, (b) Goodyear welt, (c) Turned, (d) Standard screw, (e) Pegged.

Figure 181 shows these methods. In the McKay sewed shoe method, a, the upper and the lining are held in the insole by a row of tacks driven from the outsole side and clinched at the points; the outsole is then stitched on using a single thread and chain stitch, the channel being opened up during the stitching and closed or "laid" after the stitching is completed. Sometimes an additional seam, known as "fair stitching," is run around the outsole close to the edge in imitation of the Goodyear welt. This method is comparatively cheap, but leaves a row of nail points and a seam of heavy thread inside the shoe; moreover, when it is used it is also impossible to put on a new outsole without sewing through to the inside—a stitch difficult to make by hand.

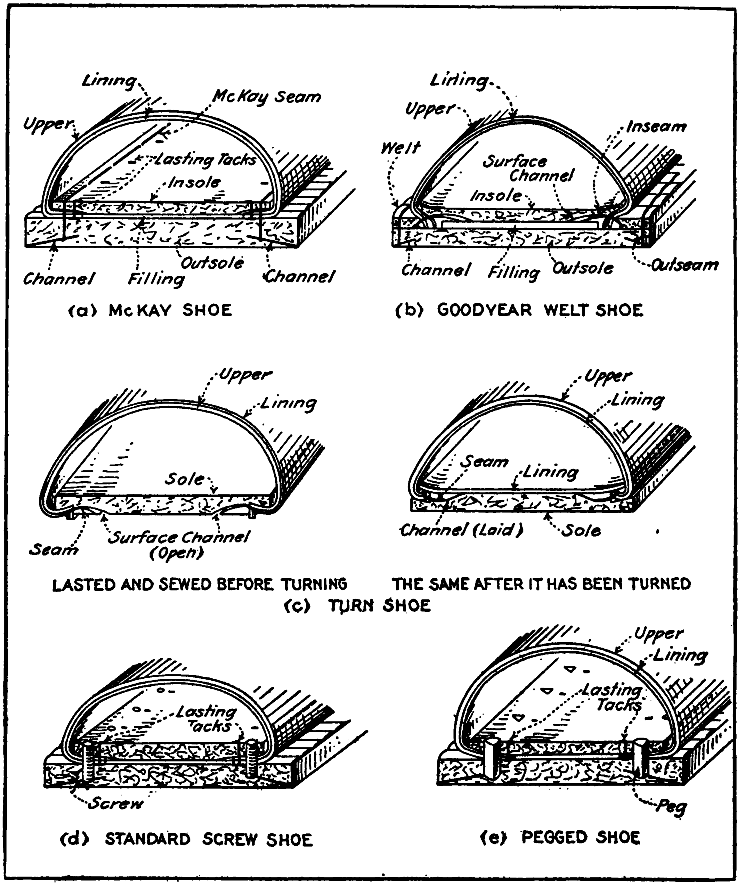


FIG. 181. TYPES OF SOLE FASTENINGS

The Goodyear welt derives its name from the strip or welt of leather which runs around the outsole between the upper and the edge of the sole, uniting the insole, upper leather and outsole by the two rows of stitching shown in the figure. Although appa-

rently complicated, the processes of this method are easily carried out by machinery, and they produce the most comfortable and durable type of shoe. Furthermore, the outsoles can be easily repaired either by hand or by machine.

Turn shoes, c, are sewed together inside out; the stitch used is similar to the inseam stitch of a welt shoe. The shoe is then turned right side out and the final operations of heeling, and so on, are performed upon it as in the case of other shoes. Turn shoes are very light and flexible, and the inner surface of the sole is smooth and free from nail points or seams of thread. This type of shoe is used for slippers, pumps, and ladies' fine footwear.

Standard screw and pegged shoes resemble the McKay type, in that tacks are used for attaching the upper leather to the insole; in the McKay shoe, however, the outsole is fastened on by threaded wire screws, while in the pegged type pegs of calendered beechwood are used. The standard-screw shoes, which lack the flexibility of sewn soles, are used for heavy, rough wear. Nailed shoes are similar to pegged shoes, except that nails are substituted for the pegs.

In 1909 the relative production of these different types in the United States was McKay, 41.5 per cent; Goodyear welt, 32.3 per cent; turned, 16.3 per cent; standard screw, 7.9 per cent; pegged and nailed, 2 per cent.

Cutting Room Machinery.—The essential parts of the clicking machine (see Figure 182) are a frame carrying a cutting block, a, consisting of maple boards set with the grain end on; a vertical plunger,

FIG. 182. CLICKING MACHINE

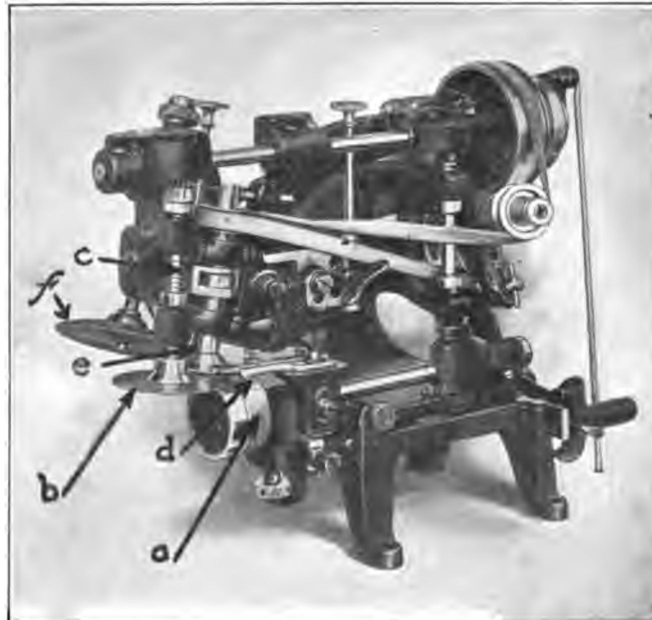


FIG. 183. AMAZEEN MACHINE

United Shoe Machinery Co.

b; and an arm, c, attached to the plunger, which rises and falls with it and may be swung so as to cover any part of the cutting block. The operator places a skin on the block, sets a light steel die or ring, about three-quarters of an inch thick and sharpened on one edge, on that portion of the skin which he wishes to cut out, swings the arm over it, and then forces the die through the leather and a slight distance into the wooden block. It might seem that the continued forcing of sharp dies into the cutting block would roughen it and soon spoil the surface. This is not the case, for the fibres become spongy and elastic because the surface of the block is kept well oiled. This method of cutting against an elastic surface is characteristic of leather manufacture.

The cutting of cloth linings is done in a similar way, but "dieing-out" machines replace the pressure arm of the clicking machine with a strong beam operated by means of eccentrics from a driving shaft below. The larger sizes have cutting blocks 96 inches long, 16 inches wide, and 10 inches high, and are capable of cutting fifty thicknesses of lining at a stroke. Clicking machines do not require such strong construction, since the operator cuts only one thickness of leather owing to the fact that he must select the best parts of each skin and place his dies to leave a minimum amount of scrap.

The skiving machine bevels or scarfs the upper leather to a thin edge, after which cement is applied to the beveled surface and the edge is folded back upon itself and pressed into place so that nothing but the grain side shows. The Amazeen machine,

Figure 183, has a feeding device, made up of a knurled roll, a, and a smooth disk, b, at right angles to it and forced against the upper surface of the feed roll by a helical spring, c. An adjustable guide, d, holds the right-hand edge of the leather at the proper point as it passes backward between the feed roll and the feed disk; a rotary disk-knife, set directly back of the feed on an inclined shaft, e, can be adjusted for various amounts of bevel; and a grinding wheel, f, mounted behind the knife, can be brought into action so as to grind the knife without removing it from the machine. For heavier work machines are used which are similar to this except that they have a stationary knife.

The skived edges are cemented on the top of a box-shaped bench machine. This has a small metal wheel with roughened surface projecting through a slot in the top which supplies the cement to the work. The inside of the machine is a cement reservoir, the adhesive being fed by a screw pump to a well under the wheel, which overflows at a fixed level so that the wheel cannot be flooded.

After being cemented, the edges are turned or folded on a machine of which there are two types. In the "Boston," the leather is laid on the table of the machine and is gripped along its entire length, about a half-inch from the edge, between two clamps that have the same curve as this edge; a block, also shaped to this curve, rises past the clamps and then approaches them, thus folding the edge back upon itself. The "Columbia" machine folds and hammers down a short length of the edge, and then feeds the

work a distance equal to the length folded over. This machine is slower than the Boston, but does not require special clamps and blocks for each shape of edge.

Stitching-Room Machinery.—Uppers and linings are stitched on sewing machines which are adaptations of the sewing machine for cloth. The essentials are the frame, the feed, and the stitching mechanism. A C-frame is used, at the upper end of which is the mechanism for moving the needle up and down, while the lower end forms the table on which the work is laid. This table may be flat and flush with the bench, for sewing flat work; or it may be convex and supported 3 to 6 inches above the bench on a vertical post or a horizontal cylinder which is part of the frame. The principal feeds are the "four-motion" and the "rotary." The four-motion consists of a serrated plate set in a slot in the table, which rises to the work, draws it backward the length of one stitch, descends, and returns to its first position; the rotary is a wheel with a serrated edge, which is intermittently rotated by a rachet and pawl. The work is held against the feeder by a presser foot or a wheel attached to the upper end of the frame.

The stitching mechanism varies according to the kind of stitch made, which may be one- or two-needle, one- or two-thread, chain stitch; one- or two-needle lock stitch; buttonhole stitch, etc. The commonest are the one-needle, one-thread chain stitch (which is strong and elastic, but has a right and a wrong side and pulls out if broken), and the one-needle lock stitch (which has two threads and does not stretch

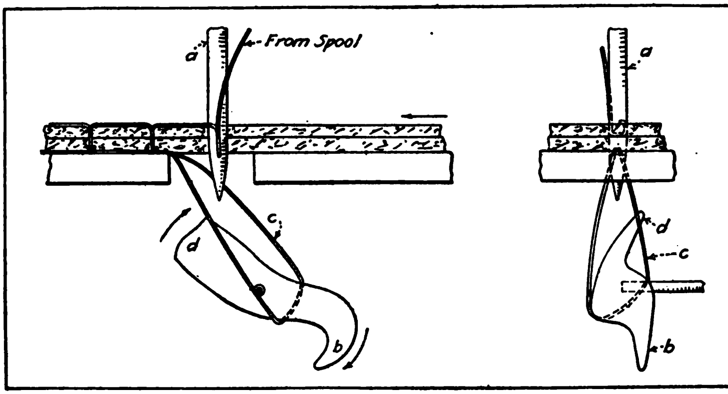


FIG. 184. CHAIN STITCH MECHANISM

easily, but cannot pull out). Figure 184 shows a common chain stitch and the mechanism that forms it. The needle, a, descends through the work, carrying the thread with it; the looper, b, rotating clockwise, catches a loop of the thread as the needle rises; the work then feeds, the loop c is spread laterally so as to encircle the needle on its next descent; and as the needle takes the position shown in the figure, the loop c is cast off from b by the extension, d, and drawn taut as the needle completes its downward stroke. Another method of forming the chain stitch is described later, in connection with the McKay sewing machine.

A typical lock-stitch mechanism, Figure 185, has a needle, a, the bobbin inclosed in case b, which is supported loosely so that a thread can completely encircle it; the shuttle, c, and shuttle driver, d, oscillated by shaft e. Both c and d move in a circular path in the frame, f. As a descends it pulls down a

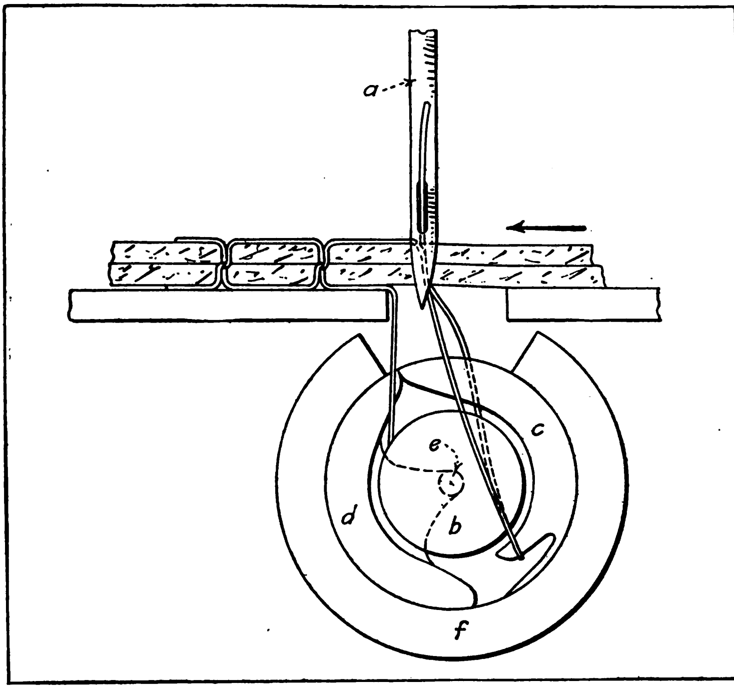


FIG. 185. LOCK STITCH MECHANISM

loop of thread which is caught on the hook of the shuttle, c, as it rotates clockwise owing to the pressure from d, and is drawn into the position shown. The shuttle rotates slightly farther, while the needle rises and a take-up (not shown) pulls the needle thread off the shuttle hook and over the left side of the bobbin, so as to loop it around the bobbin thread; then d reverses its direction, the needle thread passes out through the space opened up by the backlash between c and d, and further motion of the take-up draws the stitch taut while the shuttle, c,

and the driver, d, return to their first positions, ready for the next descent of the needle. All stitching devices, either chain stitch or lock stitch, require a tension regulator for the threads; this is usually a pair of discs or plates held together by a thumbscrew and spring, between which the thread is drawn.

The eyeletting, the buttonholing, and the making of the decorative perforations along the upper edges of tips, are also done in the stitching room. The eyeletting machine has a table on which the work is placed, a punch which descends upon the work and perforates it, and an eyelet-placing finger which receives the eyelets from a magazine, one at a time and flanged on one end, and inserts them in the perforations from the under side. A set, or rivetter, descends upon each eyelet and rivets it while the finger holds it in place. The duplex eyeletting machine sets both rows of eyelets on a shoe at the same time; thus perfect alignment is insured.

The buttonholing machine is a special sewing machine which first cuts the buttonhole with a wedge-shaped punch, and then sews it with a two-thread stitch that covers the raw edge of the hole and incloses a cord that protects it. The tip perforations are made either on a "Crown" machine, a bench machine like a miniature sheet-metal punch, which perforates the entire tip at one stroke; or on a "Royal" machine, which has a C-frame like that of a sewing machine, the needle being replaced by a punch which perforates a single hole or unit of the design and simultaneously feeds the work into

position for making the next perforation. The wooden cutting block of the dieing-out machine is replaced by a strip of paper which is fed along under the work.

Machinery of the Stock-Fitting Room.—Stripping machines are used for cutting hides into strips. The individual soles or heel lifts are then cut from the strips on dieing-out machines.

Rolling machines, which compress the sole leather to make it more durable, consist of a housing for an upper and a lower roll, gearing for driving them, a screw adjustment for varying thicknesses of leather, and a treadle for raising the lower roll.

The soles are only roughly cut to shape on the dieing-out machines, which are frequently in a separate factory, so that the accurate form must be obtained on a rounding machine. The "Planet," illustrated in Figure 186, has a circular table, a, on which is mounted a fixture, b, for holding a wooden pattern, c, shaped to the desired form of the sole. The sole is placed between this pattern and a plate, d, which is pressed down from above and is adjustable for different thicknesses of stock. A short vertical knife, e, is held in a block at the end of a swinging arm, g, which is pressed against the pattern by a spring. When the power is applied, the table and the knife rotate rapidly in a counter-clockwise direction for a little more than one revolution, to insure a complete trimming of the surplus material, and then return to their original position. During this interval the knife block has been in continuous contact with the pattern, and has made an exact reproduction in the leather stock.

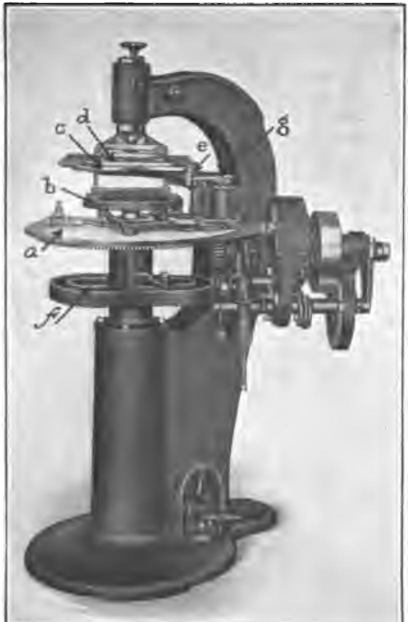


FIG. 186. SOLE-ROUNDING MACHINE

FIG. 187. PULLING-OVER MACHINE

FIG. 188. M'KAY SEWING MACHINE

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It always presents the knife edge squarely to the work; and a cam, f, shaped roughly to the outline of the sole, helps the spring to keep a uniform pressure of the swinging arm, g, against the pattern, and prevents the knife from leaving it when rounding sharp corners.

The channeling of the soles (see Figure 181) is done on machines similar to those used for heavy skiving; the work is fed between rolls against a stationary knife, which is adjusted to cut a slit in the leather instead of shaving off its surface. For Goodyear welt insoles two channels are cut simultaneously, one in the outer edge extending toward the center, and the other in the lower surface.

The manufacture of heels has developed into an independent industry. After the lifts, or separate layers, have been cut out the heels are assembled in a heel-building machine, consisting of a horizontal bed on which are set three adjustable guides or jaws, a clamp for holding the lifts together, and a nailing device for driving the required number of nails through them. There is also a cement reservoir and a row of small bins on each side of the bed, for holding sizes of lifts. The operator first places nails in a plunger plate under the bed; he then selects the proper lifts from the bins, dips them into the cement reservoir, and lays them on the bed between the jaws. When a treadle is pressed the jaws are moved together and the lifts are lined up; the power is applied, clamping the lifts together and driving the nails.

Bottoming-Room Machinery.—The machines of this department fall into three classes: lasting machines,

stitching machines, and moulding and leveling machines. Lasting consists of three operations: assembling the upper and the insole upon the last; "pulling over," or drawing the toe part of the upper down over the front end of the insole; and lasting proper, which is a continuation of the pulling-over process all around the sole. Tacking machines first nail the insole to the last and fasten the upper to the last at the heel by two tacks driven part way in. The next operation takes place on the pulling-over machine (Figure 187).

The principal parts of this machine are as follows: adjustable rests for the last and the heel; pincers, one at the toe and the others on each side near the toe; levers for shifting the positions of the pincers by hand after they have gripped the upper, in order that the toe may be exactly centered; devices for drawing the upper over the edge of the last, and for moving the pincers toward each other, thus laying the upper against the bottom of the last; and automatic magazine-fed hammers for driving temporary nails through the upper and the insole. The great advantage of the work of this machine as compared with hand lasting, aside from the saving of time, is that the tension is applied evenly all around the toe rather than at one point at a time, and the workman can see without effort whether the upper is straight and tight before he drives the tacks.

The final lasting is done on a "bed type" machine, the essential feature of which is a pair of wipers at the toe and heel. The shoe is held bottom side up in an adjustable rest; two pairs of plates are then

moved forward, drawing or "wiping" the upper closely around the edge of the sole at the heel and toe. The operator then nails down the upper all around the sole except at the heel, with a rapid-fire tacker, holding the upper with pincers in his left hand while he hammers with his right. The nails are temporary for Goodyear welt and turn soles, but are driven clear in and clinched against an iron plate on the sole of the last in making McKay, standard-screw, and pegged shoes. The wipers are then slid back, and the lasting is complete.

The stitching is done on a McKay, a Goodyear welt, or a Goodyear outsole machine, according to the location of seam and kind of shoe. Figure 188 shows a McKay machine which consists of a head, a, containing the feeding and stitching mechanism, and a turntable, b, which supports the horn, c, and the thread-waxing device, both of which are heated by steam or gas. In operation a shoe, after the last has been removed, is placed upside down on the horn, where it is held by a presser foot, and the stitching mechanism, shown in Figure 189, forms a chain stitch. The thread comes up through the horn, a, Figure 189, and is laid in the barb, c, of the needle by the whorl, b; then the needle rises with a loop of thread while the moving guard, d, is in the dotted position, but when it starts to descend the guard moves to the left and holds the loop in place, so as to enchain the loop that is drawn through from below on the next rise of the needle.

The Goodyear welt machine makes a chain stitch by the same general method, modified in details so

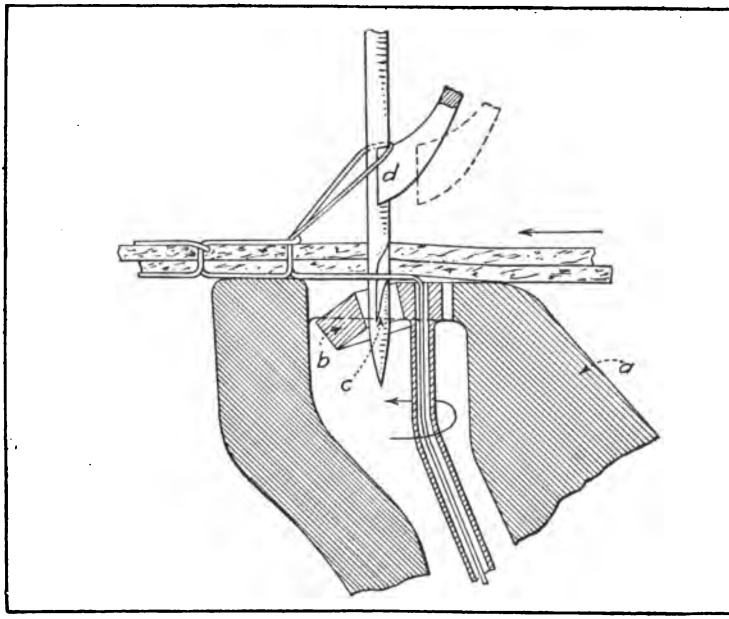

FIG. 189. M'KAY CHAIN STITCH MECHANISM

that a surface stitch (see Goodyear welt inseam, Figure 181, b), instead of a through stitch—is made. Thus the needle is curved instead of straight, and, instead of supporting the shoe on a horn, the operator holds it between a back rest and a guide which enters the surface channel and bears the thrust of the needle. There is also a guide for feeding the welt into position, which can be removed when turn soles are being stitched.

The Goodyear outsole machine makes a lock stitch by a method differing materially from that of the plain sewing machine. Instead of the needle thread's

being fed from above and the shuttle thread from below, their positions are reversed. The needle itself remains on the upper side, being barbed so as to pull the needle thread through from the under side. A reciprocating awl makes the holes, and a take-up lever draws up the slack in the threads after each stitch, duplicating in a clever and very rapid way the work of the old time shoemaker. Other essential parts of the machine, also found on the McKay and Goodyear welt machines, are: (1) steam heating system for the waxed thread, (2) thread-waxer, (3) thread-tension regulator.

Moulding and leveling machines are of two kinds: those which roll the sole, and those which shape it by direct pressure between dies. They are built with two units in tandem, so that the operator can set up one shoe while another is under pressure. The Goodyear sole-leveling machine, of the first type, holds the shoe upside down on a jack, while a concave brass roller is passed back and forth and from side to side over the sole, the pressure being applied by a treadle. The Goodyear sole-laying machine belongs to the direct pressure type; it consists of a lower head surmounted by a rubber die block, and an upper head to which the shoe is attached, the two heads being drawn together by power. The Hercules type combines direct pressure and rolling, by having the shoe-holding jack and the die that shapes the sole swing on pivoted arms, instead of sliding in guides.

Finishing-Room Machinery.—Most of this is typical buffing and polishing equipment: high-speed spindles on which are mounted milling cutters, emery wheels,

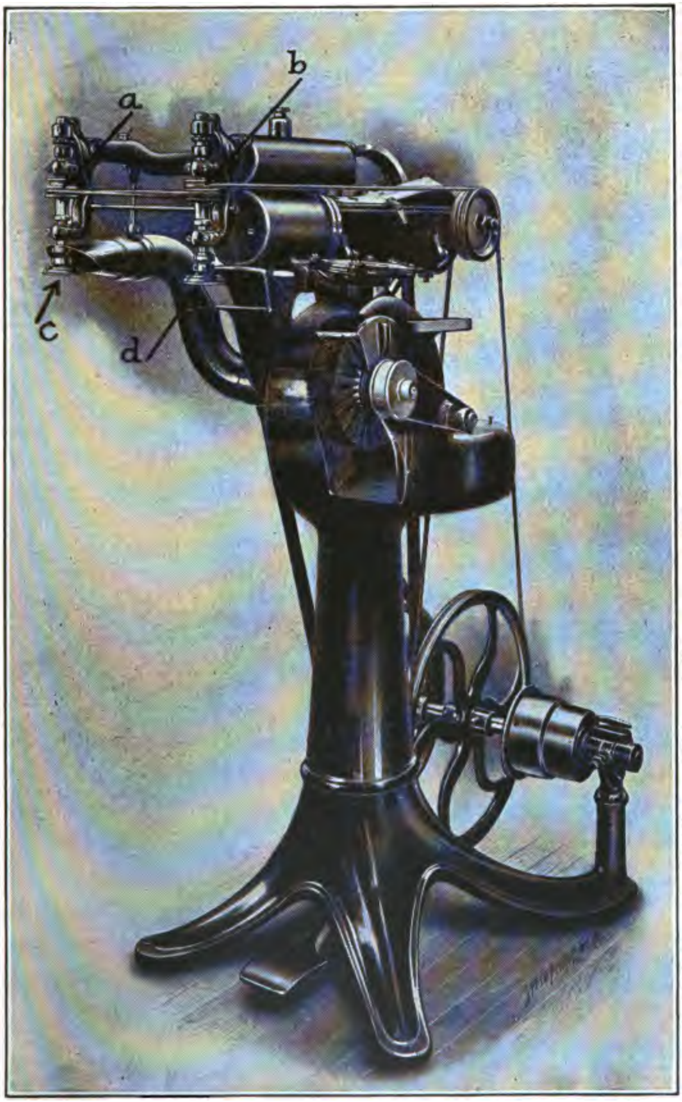

FIG. 190. NAUMKEAG BUFFING MACHINE
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sandpaper wheels, brushes and buffing wheels. The ironing machine is fitted with small blocks or disks of iron, heated by a gas flame, and vibrated or rotated rapidly so as to burnish the surface of the leather. The Naumkeag buffing machine, Figure 190, is in a class by itself. This machine has two vertical spindles, a and b, for rough and fine polishing respectively, at whose lower ends are the emery-covered rubber pads, c, d. These pads are distended by compressed air; thus a delicate, yielding pressure is obtained, and a smooth, velvet surface is given to the work.

CHAPTER XXVI

TEXTILE MACHINERY

The Fibres and the Processes.—Since the manufacture of woven fabrics is one of the oldest industries, it is natural that man's ingenuity should have devised and perfected an almost endless variety of machinery for making this product. Within the confines of a single chapter, however, it is possible to describe only typical machines, and merely to give the reader a broad survey of the subject which may serve as an introduction to a more detailed study. The four principal fibres used, in the order of their importance, are cotton, wool, silk, and linen. The processes involved are spinning, which includes cleaning and straightening the fibres, drawing them out and twisting them into yarn; weaving and knitting; and finishing, which comprises a number of processes for improving the appearance of the rough web of cloth. In the manufacture of reeled silk, a process known as throwing replaces the operations of spinning.

Cotton-Spinning Machinery.—The opening and cleaning of the fibres is done in openers and pickers. The essential part of both machines is a beater, or set of rapidly revolving, blunt steel blades, which clean the cotton over a grid. In the opener, the cotton taken from the bale is dumped into a hopper,

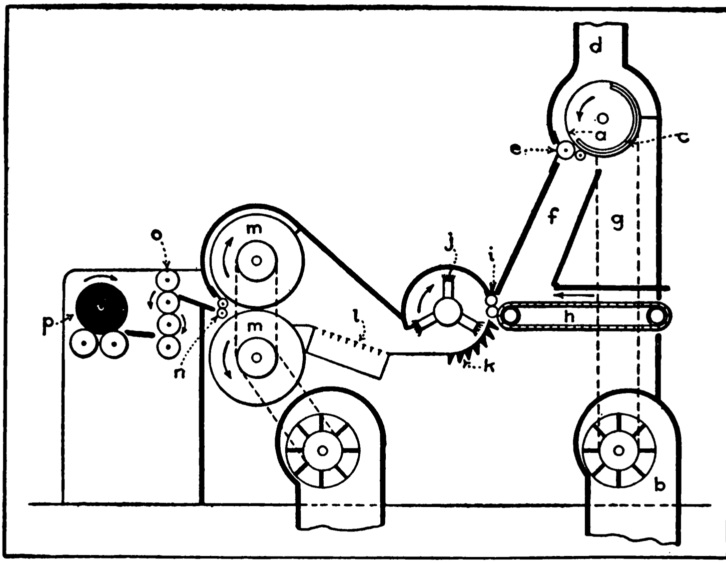

FIG. 191. BREAKER PICKER

from which it is carried on conveying aprons to a "doffer," or four-bladed drum, for a preliminary cleaning before it goes to the beater. From this point it is blown through an air duct, or "trunk," to the pickers, which are generally arranged in series of three—breaker, intermediate, and finisher.

Figure 191 illustrates the working parts of a breaker picker; a, is a screen drum connected at both ends with the intake of fan, b, and revolving around the semi-cylindrical shield, c. The cotton enters through trunk, d, adheres to the drum while dust passes through, is stripped off by roll, e, at a point where the shield, c, prevents further adhesion, and drops into the gauge box, f. This box acts as a reser-

voir to compensate for irregularities in the supply and discharge of cotton; any surplus overflows into the space, g, from which it can be removed through a door. The material in the gauge box is carried forward on the apron, h, and between the feed rolls, i, to the beater, j, which pulls it off in tufts and throws it against the grid, k, through which dirt falls, while the cotton is blown over the dust-catching grate, l, to the screen drums, m, m, which act very much like the screen, a. It is then stripped off in an even sheet, or "lap," by rolls, n, passed between weighted calenders, o, and reeled on the roll, p. The intermediate and finisher pickers have not the gauge box or the screen, a, but have racks for holding four laps, which are unwound on the apron corresponding to h.

The lap (f, Figure 192), coming from the finisher picker is practically free from dirt, and the fibres are ready to be straightened out. This is done by means of a card, Figure 192, which combs them between two surfaces covered with fine pins. The picker lap, f, is

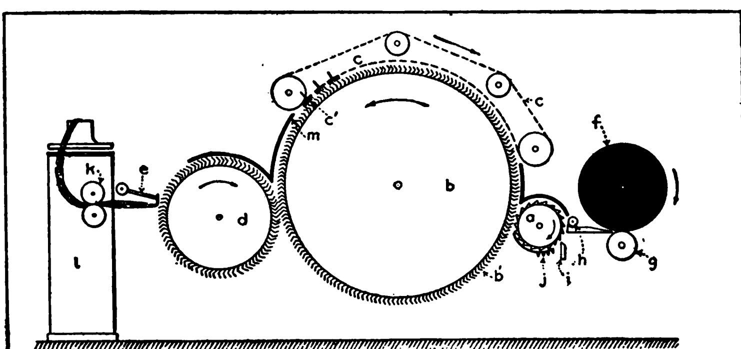

FIG. 192. COTTON CARDING MACHINE

unrolled by rolls, g and h, and presented to the rapidly revolving leader, a, which carries it over the knife, i, and grate, j, where any remaining dirt is removed, to the cylinder, b. Since the surface speed of the cylinder is more than twice that of the leader, the cotton is picked up by the forward-pointing card teeth, b′, and carried under the slowly moving flats, c, which are also faced with carding teeth. Here the pulling action on the fibres commences, and continues until the head end of the chain of flats, c′, is reached.

The cotton may travel around the cylinder a number of times, but it is eventually pulled off by the pins of the slowly revolving doffer, d; and since it rests lightly on the surface it is easily removed by the vibrating comb, e, and is fed in a lap to the calender, k, which thins it and narrows it down to what is termed a "sliver." It then passes through an automatic coiler into the can, l. One might think that if the doffer removes fibres from the card cylinder, the flats would do the same thing; this, however, is prevented by the stripping knife, m. In order to keep a card in working condition, it is necessary to grind the cylinder, doffer, and flats frequently, and to strip the doffer and the cylinder three or four times a day. For this purpose special bearings are provided on the frame, in which grinding wheels and stripping brushes may be placed when they are needed.

The Comb.—In the manufacture of long staple yarn, the cotton is passed through an additional machine, called a comb, the purpose of which is to remove all short fibres. The card slivers are first "drawn," or

stretched out, and combined into a lap about 12 inches wide, which is wound on a roll. The laps are fed to the comb cylinders, which are covered half-way around with fine needles. These pick off tufts, remove the short fibres, and pass the long ones out between detaching rolls and through a trumpet, which contracts them to a new sliver. The long fibre slivers are then fed through a calender, combined by drawing rolls, and coiled in a can. The short fibres are removed from the cylinder needles by a revolving brush, and collected in a thin lap by a doffer comb similar to that on a carding machine.

Drawing Frame; Fly Frame; Spinning Machine.—The last steps in spinning are carried out on three kinds of machines: the drawing frame, which combines the slivers from six or eight cans and draws them out by means of rollers; the fly frame, which continues the drawing process and gives the sliver a slight twist, converting it into a loose yarn, called "roving"; and the spinning machine, which twists the roving sufficiently to make it into a fairly hard yarn, at the same time drawing it slightly. Fly frames are generally arranged three in a series: the first, or "slubber," the intermediate, and the fine. Figure 193 shows a section of a fine fly frame. The course of the roving is from the bobbins, a, held in a rack called a "creel," thence through the drawing rolls, b, where the ends from each pair of bobbins are united, thence to the flyers, c, and down one arm of each flyer and on to the bobbins, d.

The flyers are mounted on spindles, e, which are driven at constant speed, while the bobbins are on

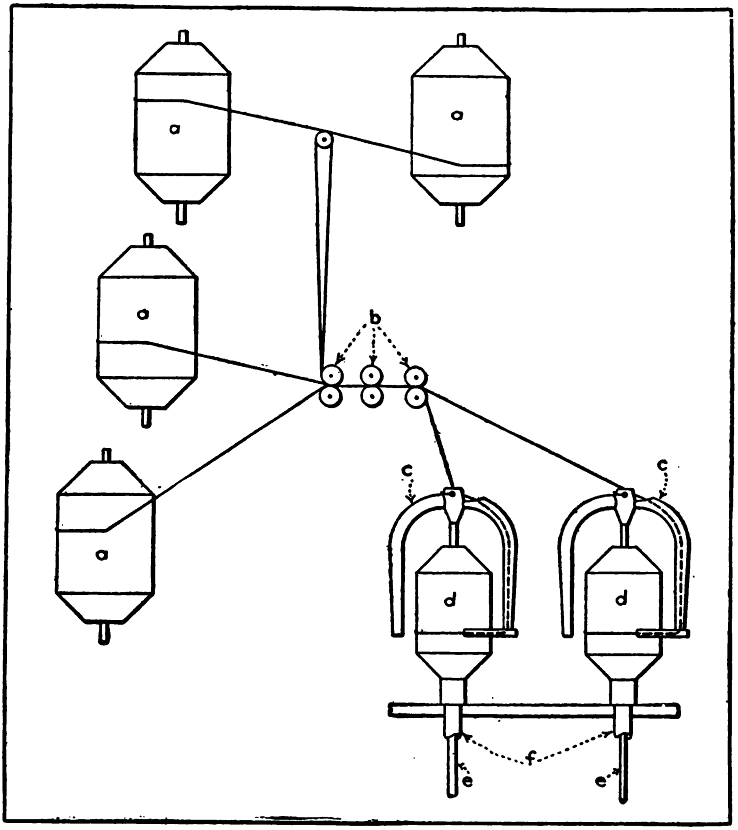

FIG. 193. FLY FRAME

concentric but independently driven spindles, f. The rotation of the flyers imparts a twist to the roving, and the excess of speed of the bobbins, d, over that of the flyers serves to wind this roving on the bobbins. In order that they may wind the bobbins evenly, the spindles, f, are carried on a rail, which is moved up and down by a builder mechanism, and the

spindle speed is decreased by an automatic tension gear as the bobbins fill up. A standard fly frame contains a row of thirty or more pairs of these flyers, set side by side as close as possible.

The spinning machine is one of three types: ring frame, cap frame, or mule. The first two are most widely used, owing to their greater simplicity and cheapness of operation. Like the fly frame, they twist and wind simultaneously, whereas the mule performs these operations successively on a definite length of yarn, and then passes on to the next length. In the ring frame the bobbin is positively driven, while a wire loop sliding on a stationary ring encircling the bobbin is moved solely by the pull of the yarn passing to the bobbin. At the same time, the friction between ring and loop is sufficient to hold the loop back and give the difference in speeds necessary for winding. All the rings of one frame are mounted on a rail, which rises and falls automatically so as to wind the bobbins evenly. In the cap frame, the bobbin and its spindle are the only moving parts of the spinning mechanism; a close-fitting stationary cap fits down over the bobbin, and the yarn, in order to reach it, has to pass under the lower edge of this cap. The resulting friction retards the yarn sufficiently to cause winding.

The mule is an extremely complicated machine and requires skill to operate and keep in repair. Its essential parts are the creel, a, Figure 194, holding the roving; a carriage, b, supporting a row of spindles, c; and a head (not shown) containing the driving mechanism. The roving passes from the

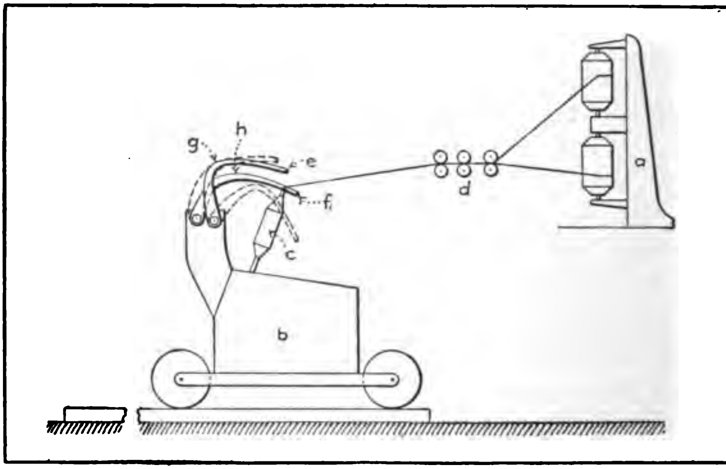

FIG. 194. SPINNING MULE

creel through draft rolls, d, to the spindles. Just before reaching these it passes between the wires e and f, attached to the winding faller, g, and counter-faller, h. The following are the steps in one cycle of operation:—

First, the carriage moves about 60 inches away from the draft rolls, while the roving is paid out. The spindles, revolving at high speed, spin or twist the yarn. Second, the carriage stops, the spindles make a few backward turns to unwind the irregularly formed turns of yarn that accumulated on top during this spinning, and the fallers take the positions shown by the dotted lines, the counterfaller acting as a yarn-tension regulator, and the winding faller as a guide in winding the spun yarn onto the bobbin. Third, the carriage runs back to its original position, and the spindles rotate slowly and

wind up the yarn that has just been spun, the fallers moving up and down in such a way as to wind the yarn evenly and under uniform tension. Fourth, the carriage stops, and the fallers return to their position.

Wool-Spinning Machinery.—All raw wool contains a quantity of grease and dirt, which must be removed in dusters and scourers. The dusters are horizontal skeleton cones with inwardly projecting pins, rotating in an air-tight chest, which acts like a tumbling barrel; the wool enters at the small end of the cone and leaves at the large end, while dust is drawn out through a fine screen above the cone and larger particles of dirt drop through a coarse screen below it. The scourers are shallow troughs, or, "bowls," about 3 feet wide and 16 to 40 feet long, fiilled with a warm solution of soft soap, into which the wool is fed and paddled along by a series of rakes, which enter the liquor vertically, advance about twelve inches, rise from the bowl, and return to their first position. This motion is necessitated by the nature of the wool fibres, which are very easily felted or matted under the action of heat and agitation, on account of the scales that cover their surface. On reaching the end of the bowl, the wool passes between squeezing rolls to the next scouring bowl or to a rinsing bowl filled with running water instead of washing liquor. After washing, the wool is carried on a perforated apron through the drier, a closed chamber about 20 feet long, where it is dried by a forced circulation of warm air.

The rest of the preparation of the fibres for the spinning frames depends upon whether they are to

be made into woolen or worsted yarn. If the former, a series of carding machines, known as the first breaker, second breaker, and finisher, performs the same functions as the cotton cards; but instead of flats there are four or five small, toothed rolls called "workers", rotating close to the surface of the cylinder, which straighten out and even the fibres. Just before they reach the doffer, a toothed "fancy roll" raises the fibres so that they are easily removed. In the case of breaker cards, they are then collected by the doffer comb, drawn into a sliver from the side, to lay the fibres irregularly, and wound into balls. The finisher card has two doffers, each of which instead of having continuous carding clothing, has alternating rings of teeth and leather about an inch wide. The slivers are taken from these rings by a "wipe roll," and pass through an apron condenser, consisting of an upper and a lower apron traveling in contact with the slivers and oscillating at the time time from side to side, the effect of which is to rub each sliver into a loose round roving. The rovings are then spooled and made into yarn on a mule.

Worsted-Spinning Machinery.—Carding machines for worsted yarns are like those used for woolen yarn, but the teeth are so spaced and the rolls so speeded as to handle the fibres with a minimum of breakage. For very long staple wools, the process known as "preparing" replaces carding. This requires a series of nine or ten gill boxes, which are machines for straightening and laying the fibres parallel, by the following simple method: The loose wool, straightened as much as possible by hand, is fed be-

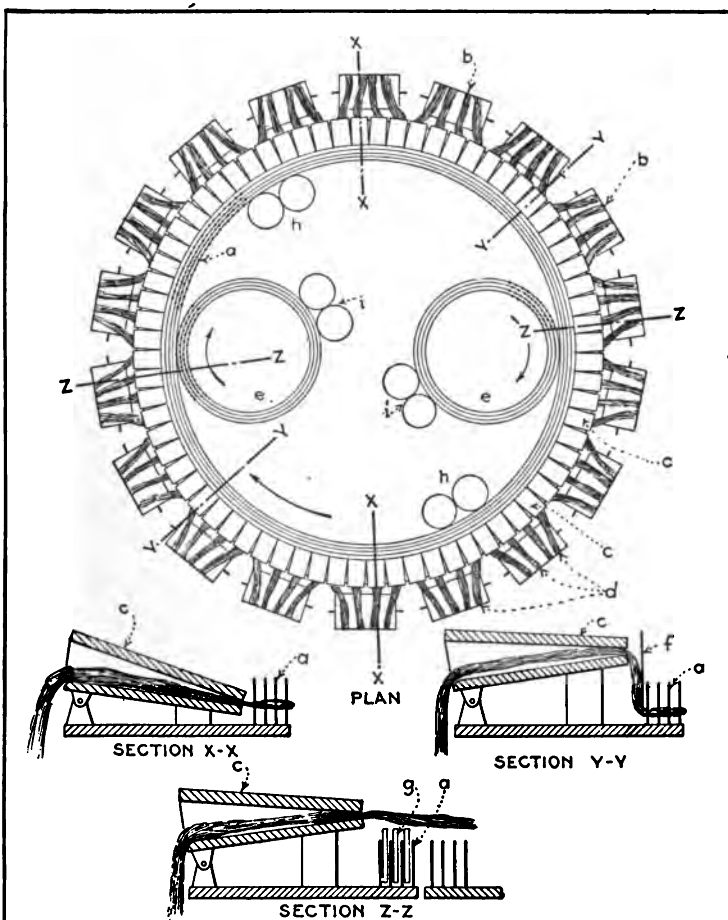

FIG. 195. NOBLE COMB

tween two fluted rolls and caught on pins projecting from a series of bars called fallers, which travel considerably faster than the rolls. These pull out the fibres. On reaching the end of the faller travel, the lap passes between a second pair of rolls, revolving at still higher speed, which pull it out still further. In each passage of the wool through a gill box, the lap is pulled out from ten to forty times its original length.

At this stage the short fibres (or "noil") which are unsuited for worsted yarn, are separated from the long ones in a comb, one form of which is shown in Figure 195. A ring, about five feet in diameter, carries several rows of pins, a, a circular creel holding balls of wool, b, and a set of conductors, c, through which the slivers, d, pass on their way from the creel to the pins. Inside this ring, and revolving in the same direction and with approximately the same peripheral speed, are the rings, e, e, also provided with pins. As seen in the sectional views, the conductors are hinged at their outer ends, and the inner ends are narrowed to keep the slivers from slipping back. At x-x, the ends of the slivers rest in the pins, as shown; at y-y, an additional length is fed out by tilting the conductors while keeping the sliver ends in the pins by means of the bar, f; at z-z, knives, g, lift the slivers off the pins; and at the point of tangency of the rings, dabbing brushes push the slivers down into the pins of both the large ring and the pair of small ones, e, e.

The further rotation of the rings causes the sets of pins to separate from each other, and the short

fibres are pulled out and stick to the pins on the rings, e, e, while the long fibres remain on the large ring, projecting inwardly in a long fringe, which is pulled off by the fluted rolls, h, and delivered in sliver form to a can. Some of the long fibres adhere to the rings, e, e; these are removed by the rolls, i, while the noil is stripped by knives (not shown) set between the rows of pins. This machine makes an extremely well-blended product, as it combines seventy-two slivers into one.

The remaining treatment in the preparation of the yarn consists of additional drawing, followed by twisting, for which gill boxes and fly, ring and cap frames are employed. Soft yarns are spun on the mule.

Linen and Silk Preparation.—Flax is received at the spinning mills in bunches of long filaments of "line," from which the short pieces or "tow" must be removed by "hackling." This is still done largely by hand, in spite of the existence of machines for the purpose. The process consists of grasping one end of a bunch of flax in the hand or holder, and pulling it through combs set with progressively finer and finer teeth. The bunches then pass through a "spreadboard," where they are combed and made into a continuous sliver, a number of which are combined and drawn repeatedly, after which they are spun on ring, cap, or fly frames.

Reeled silk, consisting of strands of six to twelve or more elementary filaments, is wound onto bobbins and "thrown," i. e., twisted and doubled with other strands. The twisting is generally done on a fly

frame, and the doubling is done on a machine that winds the threads from a number of bobbins onto a single bobbin. After each doubling, a twist is given to the thread in the direction opposite to that in which the original strands were twisted. Spun silk, manufactured from silk waste, is beaten, combed or hackled, drawn, and spun on machines that are in the main similar to those which perform these operations on other textile materials.

Weaving Machinery.—Filling thread is ready for the loom shuttle as soon as it has been wound on cops or bobbins, but warp threads require additional preparation in spoolers, warping machines, and slashers. The purpose of the spooler is to wind the warp thread from the spinning-frame bobbins onto large spools, each of which holds sufficient thread to extend the length of a warp without piecing. The spools are mounted loosely on vertical spindles arranged in a double row of sixty or more in a long machine resembling a fly frame; they are driven by friction and receive the thread from bobbins resting horizontally in wire cages. The warper combines the threads from three hundred to one thousand spools.

It consists of the following parts: a creel, or set of upright racks standing side by side, which hold the spools; a "reed," or series of vertical wires set in a rectangular frame, through which the threads are passed; a measuring roll, which is rotated by the threads as they pass over it, and is geared to a pointer indicating the length of warp that has been wound off; a comb, similar to the reed, which lays

the threads in a sheet of the same width as the beam; and the beam, on which this sheet is wound.

In the case of yarns which must be dyed before weaving, the threads are condensed into a narrow chain and wound into a ball; and after dyeing, the chain is spread out into a sheet. To keep the threads from tangling in the chain, and to simplify the piecing of loose ends if a break occurs, the comb is replaced by a "lease reed," in which each wire is perforated. Alternate threads pass through these perforations, while the others pass between the wires. At intervals of five hundred to one thousand yards, the operator raises the lease reed, lifting up half of the threads, and passes a cord between the two sheets of warp threads from one side to the other, then depresses the reed, passes the cord back again, and ties the loose ends together. By this method the warp threads are maintained in their correct places through all the rough handling involved in chaining, linking or balling, and dyeing.

The slasher, Figure 196, receives the thread from a number of warper or "back" beams, sizes it to increase its strength and smoothness, and winds it onto the warp beam of a loom. The figure shows the creel, a, holding the back beams; the size box, b, through which the warp passes; the squeeze rolls, c, c, which remove the excess of size; the steam-heated drying drums, d, d, about seven and five feet in diameter, respectively; a fan, e, to assist in drying; dividing rods, f, f, for separating the threads which tend to stick together from the sizing; a tension roll, g; and the warp beam, h, which is removed and

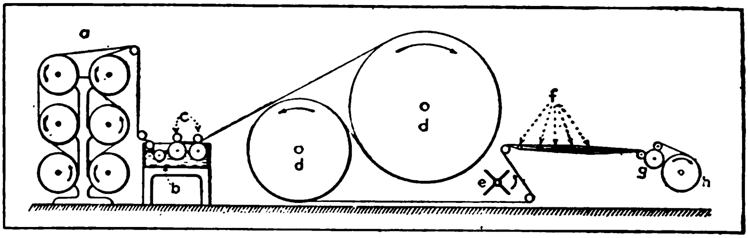

FIG. 196. SLASHER

mounted in a loom as soon as it contains the requisite length of yarn.

Mechanism of the Loom.—The loom makes a rectangular web of cloth by interlacing two sets of parallel threads—the warp, running lengthwise, and the weft or filling, running crosswise. The mechanism for a plain loom is shown in Figure 197. The warp threads, a, pass from the warp beam, b, to the cloth beam, c; alternate threads, as for example the odd-numbered ones, are drawn through the eyes, d, while the even-numbered ones are drawn through the eyes, e. A shuttle, f, carrying a bobbin of filling thread, is thrown back and forth from one side of the loom to the other, and after each traverse the position of the even- and the odd-numbered warp threads is interchanged, so that the filling is woven between the threads of the warp. Five motions are required, all derived from the shaft, g: the "shedding" motion, which separates the even- and the odd-numbered warp threads by alternately raising and lowering the eyes d and e; the "picking" motion, which throws the shuttle from side to side, each traverse being called a pick; the "beating up", occurring after each pick,

which drives the filling firmly into place by a quick motion of reed h towards the right; the "let-off", which unwinds the warp from the beam, b; and the "take-up", which winds the cloth on the beam, c, at the right of the drawing.

The figure shows the cams and the gearing for shedding and beating up, as well as one of the pick-motion cams, i. The rest of the pick motion can be seen in Figure 198, which is a front view of the "lay," the name applied to the swinging frame supporting the reed and the shuttle. The shuttle, f, is just entering the shuttle box, k, having been thrown across from the box, l, by the picking stick, j, actuated by the cam, i.

If a simple design is to be repeated, the eyes d and e are carried in three to ten or more sets, instead of two, each set being operated by its own "harness." For more complicated patterns, the harnesses are raised by levers actuated by buttons, or "risers," inserted in an endless chain which is moved forward at the rate of one link per pick. This device, called a "dobby," is fastened to the upper part of the loom and controls the design. If the same harness arrangement is to be repeated for a number of picks, as in the weaving of checks, à multiplier chain is used. This chain is started by the arrival at the working point of a button on the harness chain. The harness chain then stops until a button on the multiplier chain arrives at the working point when the multiplier stops and the harness chain starts on again. When more than one color of filling is required, a "box loom" is used, having several shuttles carried

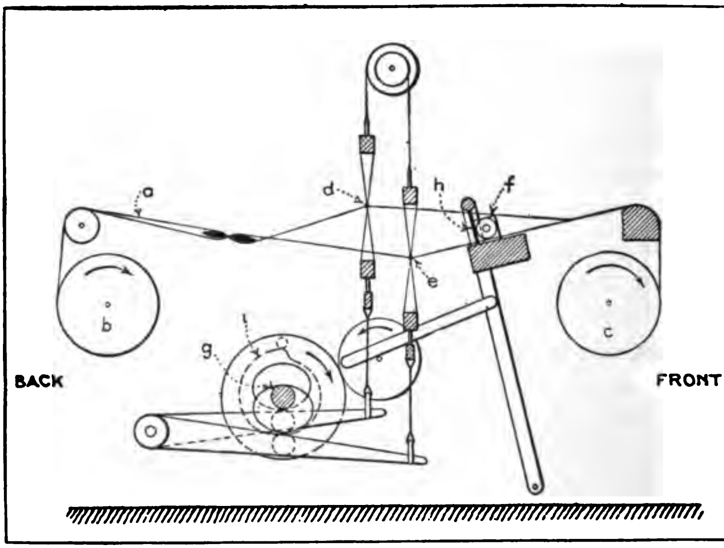

FIG. 197. PLAIN LOOM, LONGITUDINAL SECTION

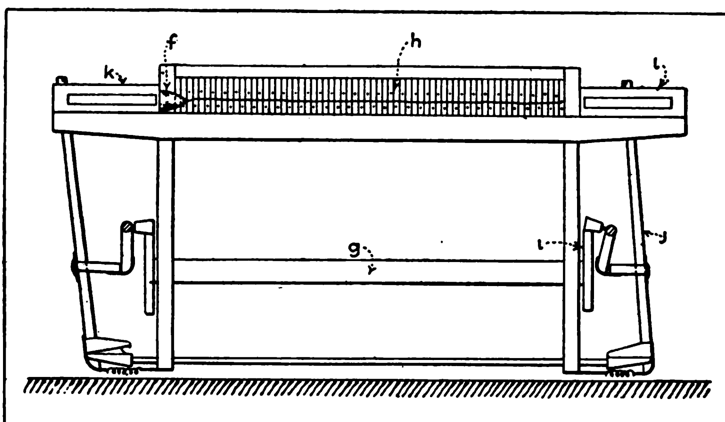

FIG. 198. PLAIN LOOM, SHOWING LAY AND PICK MOTION

on the lay in a tier of boxes, which is elevated or depressed to bring the proper shuttle into action by a mechanism similar to the dobby.

Weaving Intricate Patterns.—The most intricate patterns are woven on a loom whose "shedding" is operated by a Jacquard machine, Figure 199, which controls each warp thread by perforations in a chain of cards, just as each key of a piano is controlled by perforations in a paper roll on the piano player. The elements of the machine are a set of needles, a, equal in number to the warp threads in the pattern; hooks, b, normally resting on the grating, c; a rectangular block, d, called the cylinder, supported on trunnions, d′, and provided with holes into which the needles, a, fit; and a "griffe," or set of bars, e, for raising the hooks.

The several hooks are connected by strings, g, with the eyes, f, through which the warp is threaded. Three cards of the chain appear at h. Preceding each pick the cylinder, d, moves away from the needles, makes a quarter turn, bringing a new card into action, and returns to the position shown. This motion will force to the right all those needles for which there are no perforations in the card; and the loops in these needles will press the corresponding hooks off the griffe, so that when the griffe is raised by the shed motion, a certain number of the warp needles will be drawn up by the strings or "harness," g, while the rest will remain in place. As may be imagined, the cost of Jacquard weaving is principally due to the labor involved in preparing the cards and rigging the harness.

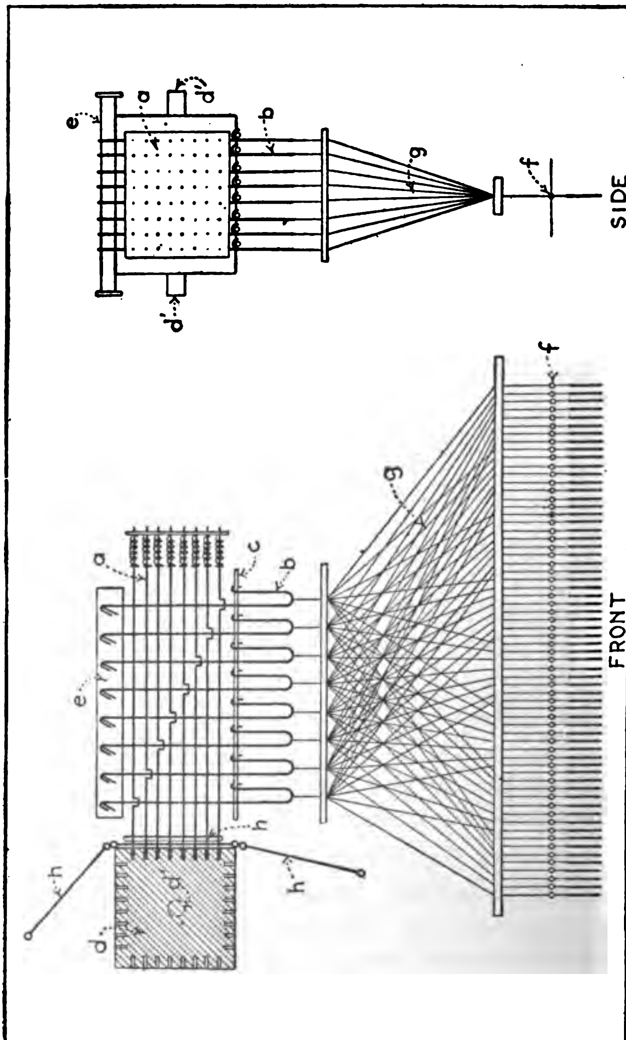

FIG. 199. JACQUARD MACHINE

Knitting Machines.—Knitting is done on two types of machine: spring needle, for plain work; and latch needle, for plain, tuck, ribbed, and other varieties of fabrics. Both types produce a tubular cloth, forming the stitches in spirals around the fabric, like the threads of a multiple screw. The stitching devices vary with different manufacturers and are complicated by adjustments for changing the kind of stitch, but the essential features of all knitting machines are these: a single or a double row of hooked needles, arranged in a circle, each of which engages one loop of the working edge of the fabric; cams or wheels for moving the needles and fabric relatively to each other in such a way as to form new stitches; and a take-up for winding the knitted fabric on rolls or folding it in cans as fast as it is made.

Figure 200 shows how this is done on a spring needle machine. The various wheels used to direct the thread are termed a feed; four of these feeds are usually attached at equal intervals around the ring, a, on which the circular row of needles, b, is mounted. The needles move past the feed from left to right, as indicated, passing in turn the holding wheel, c, which pushes the work below the barbs of the needles, sinker burr, d, which feeds the new thread under the barbs, presser wheel, e, which closes the barbs, landing burr, f, and cast-off burr, g, which casts off the old stitches and raises the new ones into the hooks of the needles. By noting each stitch in the figure, starting at the left and ending at the right, the reader can see than an additional course of stitches has been laid during the passage of the needles through the

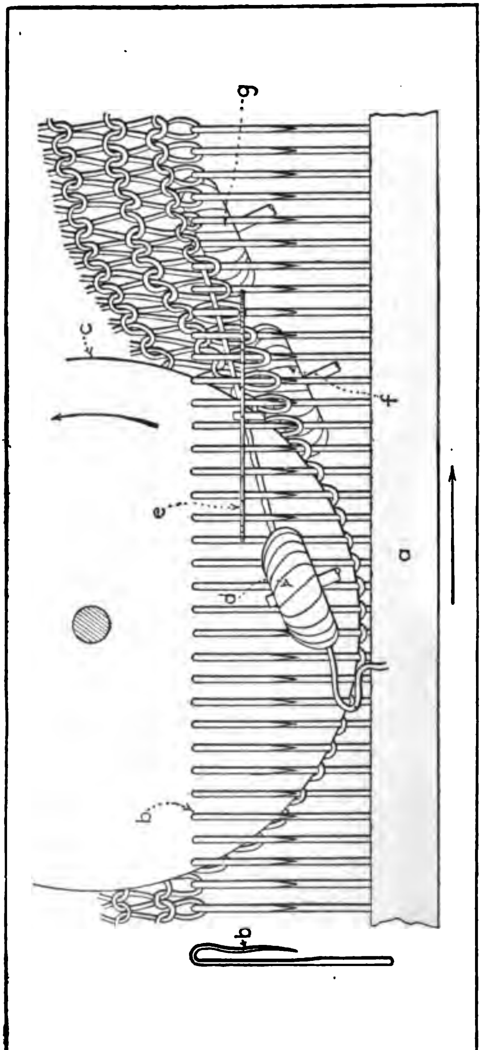

FIG. 200. ELEMENTS OF A SPRING NEEDLE KNITTING MACHINE

feed. The latch needle machine uses two rows of needles, one set vertically and the other horizontally, which are moved in and out at each feed point by means of cams.

Finishing Machinery.—Woven fabrics are passed through a number of machines; the purpose is to improve their strength, durability and appearance. The fulling mill, used for partially felting woolen goods, is a chest containing two rolls behind which is a compartment with a constricted opening. A piece of goods, saturated with soapy water, is fed between the rolls, and the ends are stitched together. The rolls are then run continuously for some time; the cloth passes between them, folds up in the compartment, is squeezed out through the narrow opening, drops to the bottom of the mill, and then repeats this cycle Under the influence of pressure, moisture, and the heat developed by friction, the cloth shrinks, at the same time becoming firmer and stronger.

The short threads adhering to the surface of cloth are removed by a singeing machine, which consists of a frame carrying rollers over which the goods are passed from one folded pile to another; at certain points gas flames impinge on the cloth, or heated copper plates come in contact with it, and by proper regulation of cloth speed and intensity of flame all the short fibres are removed. In other cases, when a nap on the surface of the goods is desired, it is obtained by a "gig," a machine whose principal part is a cylinder covered with special thistles or "teazles" grown for the purpose, which rotates close to the surface of the goods to be napped. After

napping, the surface is made uniform in a shearing machine, which brushes up the nap and then trims it to the correct length by means of a rotary cutter acting against a stationary blade.

Numerous other machines, of course, are used in textile making, for instance in the processes of bleaching and dyeing—but as these are in the nature of special equipment, detailed information should be sought in works devoted entirely to the subject.

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